ECONOMIC GEOLOGY

VOL. XXIX JUNE–JULY, 1934 NO. 4

LIMONITE DEPOSITS AT THE ORIENT MINE, COLORADO.

JOHN B. STONE.

INTRODUCTION.

THE Orient iron mine is in Saguache County, Colorado, at the west foot of the Sangre de Cristo mountains. It lies at an elevation of about 9,000 feet at the upper edge of broad alluvial fans that slope down to the waste-filled San Luis valley. Above the mine the range rises steeply to peaks more than 13,000 feet high.

The mine was discovered about 1880 and in spite of a checkered career, shipped ore in every year from 1881 to 1931, and still has some years of life ahead of it. It was, during the early years, an important source of ore for the small blast furnaces then operated at Pueblo, although its total production has been only 1,700,000 gross tons. At present the ore is used at Pueblo for mixing with hematite from Sunrise, Wyoming.

Geologically the ore deposits are interesting, for they consist of limonite derived by near-surface oxidation from replacement bodies of iron-bearing carbonate in limestone. Manganese-iron ores of somewhat similar origin have been mined at Red Cliff and Leadville, Colorado, but the Orient mine presents a clearer example of this type of iron deposit, which is uncommon in North America, although closely allied deposits are important in Spain,[1] Austria,[2] and Africa.[3]

[1] Van der Veen, R. W.: Origin of the Bilbao, Almeria, and Santander Iron Ores. ECON. GEOL., vol. 17, pp. 602–618, 1922.

[2] Lindgren, Waldemar: Mineral Deposits, 3d ed., p. 717, 1928.

[3] Geijer, Per: Geological Relations of the North African Iron Ores. ECON. GEOL., vol. 22, pp. 537–564, 1927.

GENERAL GEOLOGY.

The stratified rocks at Orient are a succession of limestones and sandstones of Ordovician to Upper Carboniferous age. These sedimentary rocks rest on a basement of pre-Cambrian granites and other crystalline rocks and have been closely folded and faulted.

The accompanying table gives the stratigraphic section of the district. The ages and correlations with formations in near-by parts of Colorado depend entirely on lithology and stratigraphic position. Interest in these Paleozoic formations has recently been renewed, and several papers on the region have been published.[4]

Leadville Limestone.—All workable ore bodies at Orient are found in a limestone that is correlated with the "Blue" limestone of Leadville, a formation widely recognized in central Colorado as a favorable host rock for ore deposits. The lower part of the Leadville limestone at Orient consists chiefly of massive, clear, blue limestone divided into small angular fragments by closely spaced joints. This limestone contains less than 1 per cent magnesia and only a few per cent of silica. The base of the formation is commonly marked by two thin beds of quartzite separated by a few feet of limestone conglomerate. The upper part of the formation consists chiefly of limestone conglomerate, limestone, and dolomitic limestone.

Intrusive Rocks.—Small irregular sills of monzonite or diorite porphyry are found in several places in or near the mine. They are mostly sericitized or kaolinized and are cut by veinlets of brown carbonate. A large body of unaltered quartz monzonite or granodiorite is intruded into the Sangre de Cristo formation at the crest of the range three miles east of the mine.

Structure.—The structure at Orient is chiefly the result of folding, but with minor faulting of two or more periods. In general the Leadville limestone in the mine strikes about north

[4] Johnson, J. H.: Contribution to the Geology of the Sangre de Cristo Mountains of Colorado. Col. Sci. Soc. Proc., vol. 12, pp. 3–21, 1929. Kirk, E.: The Harding Sandstone of Colorado. Amer. Jour. Sci., vol. 20, pp. 456–466, 1930. The Devonian of Colorado. Amer. Jour. Sci., vol. 22, pp. 222–240, 1931.

Age.	Formation.	Thickness.	Character.
Pennsylvanian to Permian	Sangre de Cristo formation	More than 3000′	Grits, sandstones, shales. Gray in lower part, red above. Graphitic shales near base.
—Erosional Unconformity—			
Lower Mississippian	Leadville or "Blue" limestone	80′ to 300′	Massive, blue, high-calcium limestone. Limestone conglomerates especially in upper part. Thin quartzite at base.
Upper Devonian	Chaffee formation	250′ to 400′	Thin-bedded light gray and yellow limestones, partly dolomitic, and interbedded quartzites. Carbonaceous shale at base in one place.
Upper Ordovician	Fremont dolomite	100′ to 200′	Massive, dark gray dolomite.
Middle Ordovician	Harding Quartzite	100′ to 150′	Vitreous quartzite, mostly thin-bedded.
Lower Ordovician	Manitou limestone	120′	Thin-bedded, cherty, dense, gray dolomitic limestone
Pre-Cambrian	Granite		Fine-grained granite, granite-gneiss, and inclusions of hornblende schist.

and dips 40° or 50° east, but the dip is not uniform and shows local minor folds. Small faults normal to the folds were probably formed during the main period of deformation, early in the Tertiary period. A normal fault that cuts the ore deposits belongs to a slightly later period of disturbance. The main period of folding occurred, or at least continued, after the intrusion of the monzonite sills.

Later Surface History of the Region.—The Sangre de Cristo range has had about its present form since early Tertiary time. Since the Miocene epoch, or even earlier, the mountains have furnished waste that has filled the San Luis valley to a depth of probably more than 2,000 feet.[5] Facet spurs near Orient suggest a possible uplift during this period.

In spite of long-continued erosion, the range is steep and

[5] Siebenthal, C. E.: Geology and Water Resources of the San Luis Valley, Colorado. U. S. Geol. Survey, Water-Supply Paper 240, 1910.

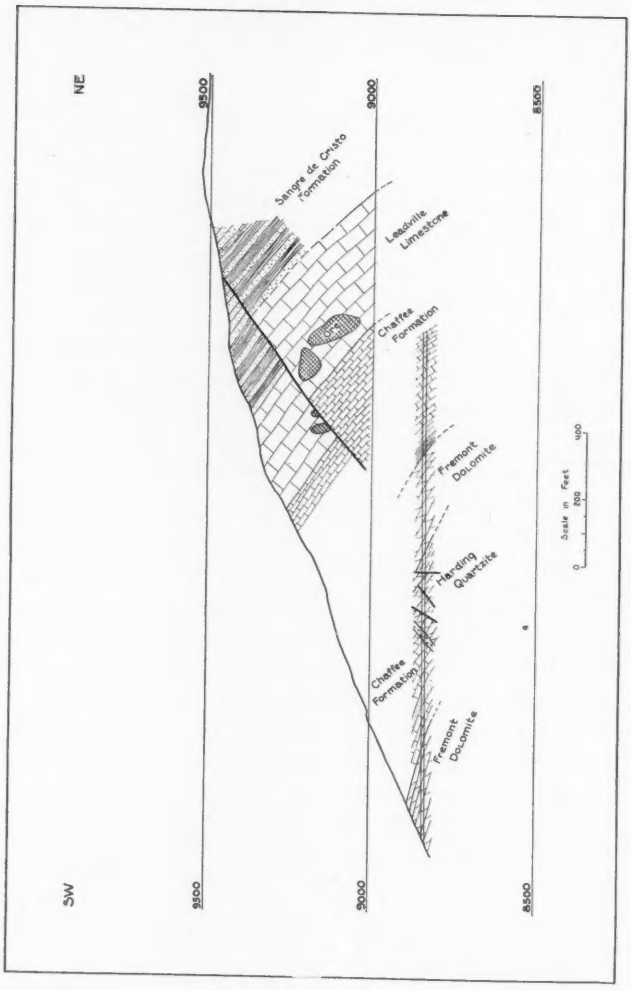


FIG. 1. Section through a part of the Orient mine.

rugged. Erosion since the glacial epoch has been slight. Notwithstanding the youthful appearance of the range, oxidation has reached great depths on the lower slopes. Rock decomposition has progressed very little, the deep oxidation being due to deep circulation of ground water induced by great relief in a limestone terrain. Before the waste filling of the San Luis valley had reached its present thickness, that relief was much greater and the water level at the mine must have been lower. The fill in the valley below Orient is at least 1,000 feet thick, and in one part of the mine completely oxidized ore is known for more than 200 feet below the present water level. It is of course possible that oxidation continued some distance below water level where the gradient of the water table was steep and the flow consequently rapid.

Solution cavities are numerous in the Chaffee and Leadville formations and range in size up to caves 60 or 70 feet wide that can be followed for hundreds of feet. The largest and most persistent water courses follow faults or certain favorable beds of limestone. Some of the limestones of the Chaffee formation were especially soluble, and connecting water courses are found in many parts of the mine near the top of that formation. As a rule the walls of the water courses are clean, but in a few places they are covered by radiating crystals of aragonite and small stalactites of calcite and aragonite. These incrustations, as far as known, occur only where iron ore is exposed in the walls of the water course.

FIG. 1. Section through a part of the Orient mine.

IRON-ORE DEPOSITS.

Limonite bodies of workable size are confined to the lower part of the Leadville limestone, commonly within a few feet of the basal quartzite, but many parts of the Chaffee and Leadville limestones are feebly mineralized, and veinlets of brown iron-bearing carbonate occur in all rocks from the pre-Cambrian granite to the Sangre de Cristo formation.

The ore bodies are irregular lenses or pipes, mostly elongated parallel to the bedding of the enclosing limestone. The long axis of the ore body may be parallel to the direction of dip or may

make a large angle with it. The largest ore body now being mined is 210 feet long by 80 feet wide in horizontal section, but some ore bodies mined in former years were larger. Ore has been developed over a vertical range of slightly more than 1,000 feet; one body has been worked continuously for 550 feet vertically and is known to extend at least 200 feet deeper.

Character of Ore.

The average analysis of ore shipped from the Orient mine during 1930 was as follows (natural basis):[6]

Fe	43.3
P	.026
SiO_2	7.87
Mn	1.43
Al_2O_3	.92
CaO	1.92
MgO	.61
S	.06
Moisture	12.3
Loss on ignition	10.17

The best ore is a hard cavernous or slaggy limonite. In places it contains remnants of cherty silica and more rarely of limestone. In addition to the hard limonite there is also a varying amount of soft yellow ocher and in places massive red ore. Small flakes of specular hematite are found in places.

An average of six analyses of the highest grade ore from diamond-drill cores gave the following (dry basis):

Fe	59.6
SiO_2	3.6
Mn	.65
CaO	1.0

By calculation the impurities are:

Quartz	3.6
Calcite	1.8
Pyrolusite	1.0
	6.4

[6] All analyses by Minnequa Works laboratory of The Colorado Fuel and Iron Company.

Subtracting these impurities and re-calculating gives 63.7 per cent Fe. The theoretical composition of goethite ($Fe_2O_3.H_2O$) being 62.9 per cent Fe, this result suggests that the Orient "limonite" is composed chiefly of the monohydrate, probably with a small proportion of admixed hematite. Exact results cannot be obtained with these commercial analyses.

The ore is nearly everywhere separated from the unreplaced limestone by a border of so-called "brown lime" consisting of coarsely crystalline brown carbonate and ocher. The "brown lime" also occurs as horses in the ore and as independent bodies without ore in limestone.

Analyses of three typical specimens of "brown lime" consisting chiefly of carbonate (Nos. 1, 2, 3) and of soft powdery ocher No. 4) are as follows:

	1	2	3	4
Insol	2.67	6.45	—	—
SiO_2	—	—	1.8	17.5
FeO	Nil	Nil	—	—
Fe_2O_3	25.4	27.7	20.0	57.2
MnO_2	1.6	1.8	1.6	4.6
CaO	35.9	32.2	38.0	1.3
MgO	.6	.6	.4	.4
Al_2O_3	—	—	.4	3.0
Loss on ignition	33.4	30.6	36.2	13.2
	99.6	99.3	98.4	97.2

The theoretical mineral combinations of these specimens are:

	1	2	3	4
$CaCO_3$	64.1	57.4	68.0	2.3
$MgCO_3$	1.4	1.2	.8	.9
"Limonite"	29.6	32.2	25.2	68.9
Pyrolusite	1.6	1.8	1.6	4.6
Quartz	2.7	6.5	1.8	17.5
Al_2O_3 (to be combined with silica)	—	—	.4	3.0
	99.4	99.1	97.8	97.2

A specimen of brown lime consisting of coarsely crystalline brown carbonate with thin white streaks of calcite and a very

little ocher was analyzed and examined in thin-section. The analysis was similar to those quoted above except that the insoluble was 12.4 per cent. Most of the section consisted of large grains of carbonate containing a fine network of "limonite," especially along cleavage planes. Other areas of the slide consisted of typical fine-grained jasperoid. Small patches of colorless carbonate occur between the idiomorphic quartz crystals.

The "brown lime" as a whole, including ocher, is higher in silica than the ore.

In places, irregular fringes of coarse, light-colored carbonates occur in the wall rock of the ore bodies. Commonly they occupy a position between the "brown lime" border and the unaltered limestone, but in places they have "brown lime" on both sides. In places the carbonates occur as intersecting veinlets in blue limestone and range from that to coarsely crystalline masses in which all limestone has been replaced. In one place coarsely crystalline carbonates contain scales of specular hematite. The carbonates vary in color from pearly white to light brown or gray. In open spaces the rhombohedral crystals have strongly curved edges. Analyses 1, 2, and 3 represent relatively unoxi-

	1	2	3	4
Insol.	6.5	1.1	3.5	.47
FeO	13.5	13.0	16.3	9.52
Fe_2O_3	nil	.65	1.85	4.71
MnO	.59	.52	1.06	.68
CaO	26.55	28.40	27.70	29.35
MgO	10.74	12.10	7.40	12.00
Loss on ignition	39.08	41.86	39.00	42.03

dized carbonates; analysis 4 represents partially oxidized carbonate.

After deducting silica and ferric oxide and re-calculating to 100 per cent, these analyses correspond to the following molecular

	1	2	3	4	5
$CaCO_3$	51.1	51.8	53.2	55.7	50.0
$MgCO_3$	24.3	26.0	16.8	26.8	21.1
$FeCO_3$	23.5	21.4	28.2	16.3	28.9
$MnCO_3$	1.1	.8	1.8	1.2	

composition. For comparison, the composition of ankerite, $2CaCO_3.MgCO_3.FeCO_3$ is given under 5.

Several specimens of these carbonates were examined by the immersion method. All fragments tested had an omega index close to 1.72; in No. 2 this index was slightly lower than 1.72 and in No. 3 slightly higher. The optical tests therefore agree with the chemical determination of this carbonate as ankerite. Some spots in the hand-specimens effervesce with dilute acid, so that it is probable that a little calcite is also present but was not detected in the small amounts of material examined optically. It will be noted that the ankerite has a much higher magnesia content than the "brown lime."

Barite occurs commonly as groups of radiating crystals in ore, "brown lime," and unoxidized carbonates. *Chalcopyrite* is a rather rare mineral, occurring as small isolated spots in "brown lime" and also in unoxidized carbonates. It is locally accompanied by minute amounts of malachite. No pyrite has been found. *Gold* to the amount of 0.01 to 0.04 ounce per ton has been found by assay in the Orient ore. *Manganese* occurs presumably as the carbonate in the unoxidized ankerite and as pyrolusite or other oxide in the ore. *White calcite* forms gash veinlets in many limestone beds but has no close relation to the ore bodies.

Origin of the Ore.

Localization of the Primary Ore.—The shape and distribution of the ore bodies at Orient show conclusively that they are not of sedimentary origin but were introduced after the consolidation and deformation of the enclosing rocks. There can be little doubt that the primary ore was formed by ascending solutions.

It has been pointed out that the ore deposits are restricted to the lower part of the Leadville or "Blue" limestone, which consists in general of massive but closely jointed, relatively pure, calcite limestone. The underlying limestones of the Chaffee formation are mostly thin-bedded, more siliceous, and in part more dolomitic, although some beds are thick, pure, limestones, similar to the Leadville formation. The upper part of the Lead-

ville formation contains more limestone conglomerate and some dolomitic limestone. In two places where ore occurs at two horizons in the lower part of the Leadville formation, it was found that the rock separating the ore bodies was a yellow limestone. An analysis of a specimen of this yellow limestone is given (No. 1), with two analyses of typical blue limestone for comparison.

	1	2	3
SiO_2	8.50	6.05	.30
R_2O_3	5.00	n.d.	.30
CaO	32.42	50.86	55.83
MgO	14.02	.52	nil

The reasons for the replacement of certain parts of the blue Leadville limestone are believed to be: (1) its purity, and (2) its closely spaced joints permitting intimate penetration by solutions.

The main feeding channels of the ore bodies are not definitely known. Carbonate veinlets and irregular replacements of "brown lime" are widely distributed but do not seem to follow any definite system of fractures. Numerous transverse faults occur, but none of them has been found to be mineralized on the foot-wall side of the ore bodies. In one part of the mine where the Leadville limestone is unusually thick, one of these transverse fractures is mineralized on the hanging-wall side of the main ore zone and has apparently served as a feeder for two ore bodies higher up in the formation. A few other mineralized cross-fractures are known.

Within the vertical zone developed by the mine it seems that the main channelways were furnished by local brecciation or fissuring of the brittle Leadville limestone by cross-folding. The mineralized fractures referred to appear to be "leakage veins" from the main channel.

The source of the solutions cannot be designated. The only igneous rocks closely associated with the ore deposits are the monzonite or diorite porphyry sills. These sills were considerably disturbed before the mineralization by movements probably attendant upon the folding of the sediments. A large intrusive

mass occurs in the crest of the range about three miles east of Orient, but no connection is known between it and the sills or the ore deposits. In general, however, the deposits are closely similar to deposits of supposed igneous affiliations, and more specifically may be referred to Lindgren's mesothermal group.[7]

Character of the Primary Ore.—Pyrite has not been found at Orient, either in the ore or in the unoxidized carbonate fringes, although chalcopyrite occurs rarely in both. The small amount of sulphur in the ore can be accounted for by the presence of barite. It is improbable that any appreciable amount of iron was deposited as a sulphide.

Iron-bearing carbonates have been deposited as veinlets that cut all sedimentary formations and the porphyry sills; the ore bodies are surrounded by rims of carbonate; and rhombohedral pseudomorphs of "limonite" have been found in the ore. Consequently it is believed that the iron was introduced and deposited as a carbonate, although the exact composition of that carbonate is not known. The only unoxidized carbonate encountered in the mine to date is in the fringes around the outside of the ore bodies. This carbonate has the composition of ankerite, but the carbonate of the "brown lime" rims in contact with the ore, is almost pure calcite with a little magnesium. The ankerite cannot be regarded as the primary form of the iron in the ore, because, in the first place, it occurs only around the outside of the ore bodies and is separated from the ore by the low-magnesia carbonate of the "brown lime" rims; and, in the second place, because the formation of goethite or "limonite" from ankerite implies a reduction in volume of six or seven to one. The porosity of the ore does not indicate such a great reduction in volume, and there is no evidence of important slumping.

It is believed that the primary carbonate ore was a mixture in varying proportions of calcite and siderite, possibly consisting chiefly of siderite in the centers of the ore bodies. If it is possible that the magnesium of the ankerite molecule may be replaced by iron until a composition is reached of essentially

[7] Mineral Deposits, 3d ed., pp. 716–717.

$CaCO_3.FeCO_3$, such a carbonate may be expected in the primary ore.

With the primary carbonate ore there were deposited a little barite, rare chalcopyrite, and minute amounts of gold. Jasperoid quartz seems to be slightly more abundant in the "brown lime" rims than in the ore. Specular hematite has been observed in unoxidized carbonates and may have been locally important in the primary ore. An analysis of a composite sample of oxidized ore showed no zinc.

Process of Replacement.—The process of replacement by which the primary bodies of carbonate were formed is believed to have been as follows: Solutions, in which iron was carried as a carbonate along with excess carbon dioxide and small amounts of other substances, rose along brecciated or fissured zones in the Leadville limestone. From the larger fissures the solutions spread throughout the blue limestone along the closely spaced joints, and from the joints, replacement proceeded outward by diffusion. At the limits of replacement the spent solutions caused the coarse crystallization of the calcite of the "brown lime" rims. The "limonite" of these rims is believed to have been partly introduced during the subsequent oxidation of the ore bodies, but a part was probably derived from the oxidation of subordinate iron-bearing carbonate. Possibly some silica occurring as chert in the replaced parts of the limestone was driven out and redeposited as jasperoid quartz in the "brown lime." The primary carbonate or carbonate mixture of the ore bodies was probably richer in iron than any of the unoxidized carbonates now known. The magnesium of the ankerite fringes may have been derived from minor replacements of dolomitic limestone.

The process of replacement at Bilbao has been clearly presented by Van der Veen.[8] In view of the similarity of the explanation given here it may be of interest to note that the present writer's conception of the process was outlined in a private report written before he had access to Van der Veen's enlightening paper.

Oxidation.—Great relief and deep water-level in a region of soluble limestones have prevailed at Orient since early in the

[8] Van der Veen, R. W.: *Op. cit.*

Tertiary period. Under these favorable conditions the transformation of iron-bearing carbonate to limonite by descending meteoric water has been complete in the central parts of the ore bodies. Some calcium carbonate was probably dissolved and removed during the process. The transformation may have depended partly on the texture of the primary carbonates. Some of the carbonate found in or near the ore has a vuggy structure and this suggests that the cavernous character of the best "slag ore" is inherited and exaggerated from the primary carbonate. Some migration of iron during oxidation is probably shown by the occurrence of "limonite" in the "brown lime" rims, although at least a part of it formed essentially in place.

The deposition of calcite and aragonite in watercourses in contact with ore has been mentioned.

Old open cuts near the portal of the present main level are mostly bottomed by iron-stained limestone of the Chaffee formation. This limestone has a rounded, hummocky surface from which a coating of ore was apparently stripped in the early mining operations. The pits lie along the downhill side of the ore zone, and some limonite ore of the type mined underground crops out in them. Several feet of coarse bouldery gravel was stripped from over these pits. In the long period of erosion before the glacial epoch, surface water running over the outcrop of the ore zone apparently leached iron from it. The iron-bearing water then soaked into the surface limestone lying downhill from the ore zone and replaced it, forming a comparatively wide but very shallow zone of transported ore.

Oxidation probably still continues, but with lessened effect due to a rising water table coincident with the filling of the San Luis valley.

ACKNOWLEDGMENTS.

I am indebted to The Colorado Fuel and Iron Company for permission to publish this paper, and to G. H. Rupp and W. S. Burbank for criticizing the manuscript.

PUEBLO, COLORADO.

THE ORE DEPOSITS OF LOS LAMENTOS, CHIHUAHUA, MEXICO.

WILLIAM F. FOSHAG.[1]

INTRODUCTION.

THE so-called limestone or *manto* type of ore deposit of Mexico embraces some of the most important and productive ones of this region. Included in this class are such important camps as Santa Eulalia, Mapimi and Sierra Mojada, with production records of many millions of dollars in silver, lead and zinc. The characters attributable to this type of deposit may be listed as follows:

1. In form, huge chimneys cutting limestone beds, or *mantos* following beds.
2. The total absence of visible intrusive rocks other than small post-ore intrusives.
3. The general absence of silicate mineralization.[2]
4. Their association with anticlinally folded ranges.
5. Ore minerals of sulphides of lead, zinc and iron and their oxidation products, often with important quantities of silver; copper is usually totally absent.
6. Common development of dolomitization about the ore bodies.
7. Highly ferruginous character of the mineralization (marmatite, pyrrhotite, iron silicates).

The simplest of these deposits is that of Los Lamentos, as developed in the Erupcion and Ahumada mines. Here a single manto faithfully followed a " favorable " bed for the entire distance of its developed length. Whether or not this manto is an offshoot from a large chimney, as is the case of the mantos of Santa Eulalia, cannot be determined at this time.

[1] Published with the permission of the Secretary of the Smithsonian Institution.

[2] Except at Santa Eulalia, where there are large but local bodies of iron silicates.

Through the courtesy of the late Mr. Carl Mohler and of Mr. Charles Dobble, superintendents of the mines, I was privileged to spend a total of five weeks in this district in 1926 and 1927. The district had previously been visited and described by Rickard.[3] After my first visit the district was studied by F. L. Ransome, who mapped the geology of the Los Lamentos Range. Dr. Ransome introduced the formational names used in this article and was the first to recognize the thrust fault that characterizes the northwestern section of the range. The fossils collected have been examined by Dr. T. W. Stanton, to whom I am greatly indebted for determinations and remarks concerning the age of the beds. Due to the low price of metals and a strong flow of water in the lower levels of the Ahumada Mine, the mines of the district were closed and the connecting railroad abandoned.

Geography.

The Los Lamentos district lies in the northern part of the State of Chihuahua, not far south of the United States boundary line. It is 115 miles southeast of El Paso by automobile road and 40 miles east of Villa Ahumada, a station on the Mexican Central Railroad. A branch railroad line, the F. C. Chihuahua y Oriente, connecting at the station of Lucero, formerly ran to the camp. The region is a barren and unwatered one, characterized by broken limestone ranges and broad grassy valleys.

The Sierra de Los Lamentos is a steep limestone block with a general east-west trend and rises about 2,000 feet above the plain. The front or southern slope is exceedingly steep and presents to view a succession of limestone beds (Fig. 1). The northern slope is a dissected dip slope, rather rugged in appearance. To the northwest is a smaller hill, similar in structure to the main range, called Buena Suerte Hill. There are two main eminences on the crest of the main range, a high dome of limestone near the middle of the range, referred to as "The Bufa" and a sharper peak near the western portion of the range called

[3] Rickard, T. A.: Eng. & Min. Jour. Press, vol. 118, pp. 365–373, 1924.

FIG. 1. Front of the Sierra de Los Lamentos, showing the steep limestone cliff or *bufa*. The peak at the extreme left is Labrador Peak, the dome on the right is "The Bufa."

Labrador Peak; between these two eminences lie the important ore bodies of the district.

STRUCTURE.

The general structure of the Sierra de Los Lamentos is that of an arched faulted block[4] (Fig. 3) in which the beds dip

FIG. 2. Front of the range showing its stratigraphy. The dip of the beds is away from the observer at an angle of 14°.

[4] The Sandia type of N. H. Darton. Paper presented before the 40th Annual Meeting of the Geological Society of America. Abstracted in Bull. Geol. Soc. Am., 39, 182, 1928.

gently (14°) to the north. To the west the limestone beds gradually pass under the plain, and to the east they take on an abrupt change in strike for a short distance. The range front, viewed from the valley, shows in a striking manner that the limestone beds emerge gently from the plain to the west, bow in a gentle arch to a maximum at the Bufa, and gradually decline again to the east. T. A. Rickard [5] states that the bold scarp is due to erosion, not faulting, yet the Sierra de Los Lamentos, both in physiography and by analogy with similar limestone blocks of the Plateau Region, is obviously a faulted, upthrusted ridge. A moderate alluvial slope cut by shallow arroyas flanks the range on the south.

The only feature that greatly disturbs the continuity of the sedimentary sequence is a thrust fault that is exposed at the extreme northern segment and is traceable along the northwestern flank of the range. This fault, called by Ransome the Sonora Fault, separates the sedimentary beds of the main range from those of Buena Suerte Hill. There are too, a series of small normal faults in the vicinity of Labrador Peak. The displacement along these faults is not great nor do they alter the appearance of continuity of the beds to any marked degree.

Stratigraphy.

The rocks of the Sierra de Los Lamentos are entirely limestones of the Comanche series of Cretaceous age. Abundant fossils are encountered in many of the beds. The beds of the front face of the range fall naturally into four groups, although they are conformable and fossil evidence indicates no great difference in age (Fig. 2).

Angela Formation.—This formation, locally referred to as Blue Limestone, is exposed along the foot of the range for short distances on either side of the camp. The lowest portion consists of thin-bedded limestone; the upper beds are thicker and more massive. The limestone is fine-grained, breaks with a rough conchoidal fracture, is comparatively free of later veins of calcite and is only sparingly fossiliferous. A few poorly preserved

[5] *Op. cit.*, p. 365.

sponge remains and scattered foraminifera were found. Thickness, 500 + feet.

Los Lamentos Formation.—Above the Angela limestone is a thick-bedded limestone rich in fossils and rather abundantly fractured and traversed with later veins of white calcite. This is light gray in color, often mottled with pink, is of a fine grain and when free of veins breaks with a rough conchoidal fracture. Although fossils of the genus *Caprina* are abundant in this formation, good specimens are difficult to collect. Because of its thick-bedded character this formation forms steep and bold outcrops. Average thickness, 400 feet.

San Vicente Formation.—Above the Los Lamentos beds, the bufa presents a bench where thin-bedded and lamellar limestone outcrops. This is followed by a thick bed of massive limestone and this in turn, by another series of thin, lamellar beds. These have been grouped together as the San Vicente formation. Many of the lower beds as well as the upper beds are foraminiferal, being made up in large part of abundant small disks of *Orbitulina texana* (Roemer). The color of these beds is dark gray ranging to almost black. They yield a fetid odor when struck with the hammer and hence are locally called the Fetid limestone. Fossils other than the *Orbitulina* are not well preserved although *Gryphaea, Hemiaster,* and other forms have been found in the upper beds. The average thickness is 500 feet.

Bufa Formation.—The crest of the ridge is capped by a thick limestone which forms steep and in most places unscalable cliffs. The San Vicente formation below merges gradually into this limestone so that an exact dividing line between the two cannot be drawn. The limestone is light gray in color with mottled light pink. Fossils are abundant although good material is difficult to collect. Corals and gastropods are prominent and include such genera as *Lunatia, Requienia,* and probably *Cidaris.* Much of the northern slope of the hill consists of this limestone and its thickness exceeds 1,500 feet.

Sonora Formation.—A light, fine-grained to friable gray limestone forms the lower northern slopes of the range and, accord-

ing to F. L. Ransome, is thrust upon the Bufa beds. No fossils were found in this formation. Its thickness is in excess of 500 feet.

Tlaxcala Formation.—Separated from the main ridge of the Sierra by a low pass is Buena Suerte Hill, the lowest portion of which is made up of a thick-bedded fossiliferous limestone forming low cliffs. Although the fossils are abundant, little material was collected that was well preserved. These include *Ostrea?, Requienia?* and *Nerinea?* The thickness is 500 feet.

Buena Suerte Formation.—Above the Tlaxcala formation, thin bedded limestones form a prominent bench on the hill slope. The lower beds present a blotchy appearance due to the presence of numerous fossil sponges. Near the base, too, are beds with abundant sea urchins (*Hemiaster*) which, in favorable places can be collected in abundance. *Cidaris, Cyphosoma, Pecten, Gryphaea* were also found. The upper beds yielded poorer fossil material and they grade into the more massive limestones. The thickness is 500 feet.

Triste Formation.—The top of Buena Suerte hill and a portion of the low outlying hills are made up of this limestone, which is thick-bedded and forms the cliff which tops the hill. It is moderately fossiliferous but no determinable species were collected. Its thickness is 500 feet.

Correlations.—Indications from the fossil fauna are that the three limestones in the lower part of the section (Angela, Los Lamentos and San Vicente) are referable to the Trinity group of the Comanche series. From its lithology and the few fossils collected, the Bufa limestone seems to represent the Edwards limestone of the Fredericksburg group. The echinoids of the Buena Suerte limestone are somewhat suggestive of the Washita fauna but all are species which range a good deal lower and it may well be that the rest of the section above the thrust fault is essentially a repetition of those beneath it and that no rocks younger than the Fredericksburg group are exposed here. There is a slight suggestion of such a repetition in the occurrence of sponges, echinoids (*Hemiaster*) and *Ostrea* (*Alectryonia*) beneath the Bufa in one section and beneath the Triste in the other.[6]

[6] Stanton, T. W. Report to the writer.

Mineralogy.

The deposit is largely made up of oxidized lead and zinc minerals. Oxidized iron minerals are common. Sulphide minerals are rare and copper minerals are almost totally absent. Gangue minerals include calcite, dolomite, gypsum and sulphur.

Galena.—Residual lumps of coarse cleavable galena were observed in the lower levels of the mines but are not abundant.

Sphalerite.—A small pocket of unaltered sulphides on the tunnel level contained fine-grained dark-colored sphalerite.

Pyrite.—A small amount of pyrite was associated with sphalerite.

Cerussite.—The carbonate of lead was the prime ore mineral in the lower levels of the *manto*. For the most part it consisted of "sand carbonates" or of sandy pockets in soft earthy iron oxides. Spongy masses, colored dark by hematite and rarely containing small blebs of galena, were also encountered. A few poor crystals were found.

Vanadinite.—The chlorovanadate of lead was abundant in the lower levels, especially near the water level, in places forming spongy masses of great purity and constituting an ore of vanadium. It occurred in fine to large crystals of a raisin-brown or hair-brown color. Smaller crystals were well formed but simple in habit and larger ones were barrel shaped and generally hollow. The larger bodies of vanadates contained large vugs lined with brilliant crystals. In places wulfenite crystals were partially or completely replaced by vanadinite.

Descloizite.—The vanadate of lead and zinc was usually found in close association with vanadinite and wulfenite, or more rarely with calcite and willemite near the borders of the ore deposit. Pure spongy masses of lustrous crystals surrounded vanadinite bodies. Irregular nodular masses of crystals were found in zones of broken rock. Descloizite also replaced wulfenite crystals.

Anglesite.—The sulphate of lead was abundant in the Erupcion mine and to a lesser extent in the Ahumada mine. In the Erupcion mine pure masses of fine-grained gray anglesite formed important ore bodies. Coarse "sand sulphate" was abundant,

much of it consisting of small rough crystals, the coarsest reaching 1 cm. in length. Nodular masses with an agate-like banding and sometimes with a core of galena were abundant at one time. Perfectly formed but etched crystals in some places exceeding 6 cm. in length were frequently found embedded in gypsum or sulphur. In the lower levels, anglesite was less evident and was usually in porous ferruginous masses. At the outcrop in earthy red hematite, were found nodular bodies some of which showed the original cleavage of galena.

Plumbojarosite.—The basic sulphate of lead and iron formed pure masses in the Erupcion mine. Its color was pale ocherous brown and the structure was somewhat flaky so that the mineral possessed silky sheen.

Wulfenite.—The molybdate of lead was found abundantly in the Ahumada mine, although rare or absent in the Erupcion mine. Spongy masses of brilliant orange-colored crystals were plentiful. These aggregates rarely had a central nucleus of galena or cerussite. The usual platy crystal habit of wulfenite was rare at Los Lamentos, the usual one being the steep pyramidal or prismatic type which is ordinarily rare. It was suggested that this unusual crystal habit was due to the presence of some vicarious element but analysis showed these crystals to be very pure $PbMoO_4$.

Willemite.—Except for descloizite the normal silicate of zinc appears to be the most abundant of the zinc minerals. It forms spongy aggregates of small hexagonal prisms, colored chocolate brown by iron. White tufts and crusts of needle-like crystals were occasionally found in the ocherous red hematite.

Hydrozincite.—The basic carbonate of zinc forms white chalky masses or small banded and streaked bodies with red earthy hematite.

Hematite.—This mineral is abundant in various earthy or fine-grained forms. In the outcrop it is usually ocherous red or dark reddish brown. A scaly texture is evident in places, as is a silky sheen inherited from some pre-existing mineral. In the lower portions of the ore body the hematite is mostly dark bluish black to entirely black, although some of it is fine-flaky in texture with

a silky luster. This last type forms sandy to friable masses and under the microscope is seen to be made up of small circular disks, the thinner ones being blood red in color.

Goethite.—Although this hydrous oxide of iron is rare, it is occasionally found near the surface where it forms thin, lustrous crusts in cavities in limonite.

"Limonite."—This mineral is confined to the surface portions where it forms buff-colored or compact brown masses.

Brochantite.—One small specimen of the basic sulphate of copper was found associated with gypsum.

Gangue Minerals.—In the Erupcion mine, gypsum and sulphur formed large masses closely associated with anglesite. The sulphur was usually massive although small crystals were abundant in vugs in anglesite. Gypsum formed flaky bodies in the ore or occurred in the caves as efflorescent forms and as silky fibers. Medium-grained dolomite is plentiful. Calcite is present in many places as secondary crystals associated with the ore minerals.

Ore Deposits.

At several places along the slope of the range, masses of fine-grained and fossiliferous limestone have been replaced by medium-grained dolomite. Tongues of this recrystallized material penetrate the unaltered limestone and the mutual boundaries are rather sharp. The recrystallized rock is medium-grained and in places somewhat vuggy. The color ranges from light gray, veined with white, to pale reddish brown. As shown by chemical analysis, this change coincides with an almost complete dolomitization of an originally low magnesia limestone.

The known ore deposits of the district are associated with this dolomitized limestone, in fact, the recrystallized rock forms an aureole about the ore pipes. There are, however, several large areas of dolomite in which no traces of ore have been discovered. The width of the dolomite zone about the ore pipes is variable; the average is perhaps fifty feet, but in places is much wider, and in a few other places the ore lies directly against unaltered limestone.

ANALYSIS OF UNALTERED AND RECRYSTALLIZED LIMESTONE, LOS LAMENTOS DISTRICT.

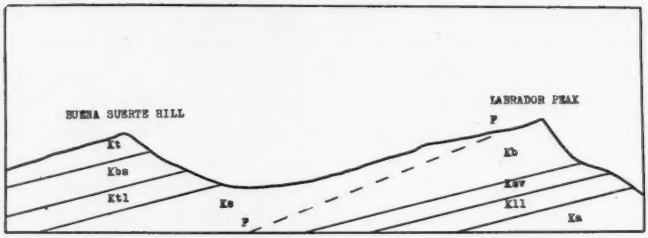
W. F. Foshag, Analyst.

	Fresh	*Recrystallized*
CaO	50.40	31.32
MgO	4.79	20.70
FeO	0.11	0.26
Fe_2O_3	None	0.43
Al_2O_3	0.34	0.24
Ign. loss	44.12	47.22
Insol.	0.28	0.44
	100.04	100.61

Three distinct ore shoots have been found. The Erupcion-Ahumada *manto* is by far the most important. The upper portion constitutes the ore body of the Erupcion mine; its continuation in depth, that of the Ahumada mine (Fig. 4). Slightly to the west is the Berenda ore body, which may be an offshoot of the main pipe but its downward extension is in doubt. Some distance to the east lies the Mexico ore body, a small pipe that was early worked out. All of the mines are controlled by the Compania Minera de Plomo, S. A.

Though not large, the outcrop of the ore pipe at the Erupcion mine is conspicuous because of its red color. It consists of hematite in various forms, some of which is ocherous red, whereas some is clinkery and dark bluish black. There is also massive iron oxide, the cavities of which are lined with a varnish-like goethite. Dark purplish red hematite with a fine scaly texture, probably derived from jarosite, is present. In this ferruginous mass there are firm lumps or sandy masses of anglesite. There are also masses of bony willemite and cavities are lined with delicate needles of the same mineral. No other minerals are conspicuous.

The ore body of the Erupcion and Ahumada mines is a single and continuous pipe (Fig. 4) confined entirely to the lower portion of the Los Lamentos formation, at or near its contact with the Angela limestone. The dip of the pipe is that of the beds, 14° to the north in the Erupcion and upper portions of the



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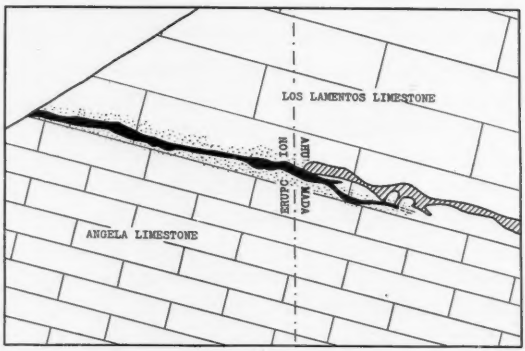

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FIG. 3. Structure and stratigraphy of the Sierra de Los Lamentos. *Ka,* Angela limestone; *Kll,* Los Lamentos limestone; *Ksv,* San Vicente limestone; *Kb,* Bufa limestone; *Ks,* Sonora limestone; *Ktl,* Tlaxcala limestone; *Kbs,* Buena Suerte limestone; *Kt,* Triste limestone. *F – F,* Sonora thrust fault.

FIG. 4. Ore manto at Los Lamentos. *Black,* ore body; *lined,* caves; *stippled,* dolomitized limestone. The apparent thinning of the manto at depth is due to a spreading of the ore body. (Somewhat diagrammatic.)

Ahumada mines and somewhat greater in the lower portions of the Ahumada. As far as can be determined, none of the ore has found its way into the Angela limestone, although this limestone is dolomitized in places for a short distance. One of the remarkable features of this deposit is the restriction of the ore to the lower portion of the Los Lamentos limestone.

The upper portion of the ore pipe is fairly regular. It has a thickness of about 10 meters and a width of 50 meters or more. In the Ahumada ground the ore bodies are more irregular. Here the pipe passes under a series of limestone caves where the hanging wall of the ore body consists of a mass of limestone boulders that have sloughed from the roof of the caves.

The ores of both mines are entirely oxidized. The only sulphides observed were rare irregular residual lumps of coarse cleavable galena. Anglesite and cerussite are the chief ore minerals but vanadinite and wulfenite are sufficiently abundant in places to make rich ore. Some small ore bodies were, in fact, largely vanadinite and the ore was shipped for its vanadium content. Descloizite is common. The lead ores carry small amounts of silver, commonly about one ounce silver to the per cent of lead. Zinc minerals are widespread although no commercial bodies of this ore were encountered.

In the upper parts of the manto, anglesite was the chief ore mineral and formed pure masses of compact ore running as high as 65 per cent Pb. There was also a fine to coarse "sand" ore made up of small, loose crystals of the same mineral. Gypsum and sulphur were abundant and commonly carried large and well-formed crystals of anglesite. Sulphur was also commonly associated with the more massive anglesite. Large bodies of plumbojarosite, assaying 19 per cent Pb, were also encountered in this part of the pipe.

In the Ahumada mine the ore changed to a ferruginous lead carbonate ore of variable richness. Some ore consisted of cerussite colored black by associated hematite. Other portions consisted of a fine silky blue-black hematite with nests and streaks of cerussite. As mined, the ore was earthy black "muck" and the ore minerals were hardly apparent. Such ore averaged 30 per cent or better in lead. At the 5th level, wulfenite, vanadinite, and descloizite began to appear in abundance and at the 7th level (just above the water level) they constituted a good portion of the ore. Several stopes were worked almost entirely on loose spongy masses of raisin-colored vanadinite needles as-

saying 65 per cent Pb and 12 per cent V_2O_5. These masses were bordered peripherally by crystallized descloizite. On the 7½ level the ore was a mixture of crystals of cerussite, wulfenite, vanadinite and descloizite. In other stopes there were rich sand carbonates with scattered pipes and nests of wulfenite.

Zinc minerals were widespread but not abundant; most important of these was willemite. Some masses were made up of a loose and porous sponge of crystals. Secondary calcite was commonly present and occasionally small platy crystals of wulfenite were observed. Willemite showed a decided preference for the walls of the pipe but was nowhere sufficiently abundant to constitute an ore. White, chalky hydrozincite banded with red ocherous hematite was found in small bodies.

There is definite evidence that, in part at least, the oxidized minerals followed a definite sequence. Residual galena lumps were surrounded by the usual zones of anglesite and cerussite. Galena and cerussite formed the cores of nests of wulfenite. Wulfenite was in places partially or wholly replaced by vanadinite and descloizite, and the latter was in many cases distinctly later than the vanadinite. These relationships, together with the fact that the molybdates and vanadates showed a decided concentration at and near the water level, suggest that these elements had migrated gradually downward to produce a secondarily enriched rare metal zone. A similar relationship was observed in the Ojuela mine at Mapimi, Durango.

There is evidence, too, that some of the ferruginous lead ore had first passed through a plumbojarosite stage. Specimens were found in which this change is definitely taking place. Flaky hematite resembling plumbojarosite in texture and associated with anglesite crystals was not uncommon. It is probable that the fine, flaky black hematite associated with cerussite was derived from plumbojarosite. In the Potosi mine at Santa Eulalia this change of plumbojarosite to a mixture of hematite and anglesite is more apparent.

Origin.

The ore deposits of Los Lamentos offer little information as to the ultimate source of the mineralizing solutions. In conjunction with the data furnished by other Mexican districts of similar character, however, it can be quite confidently stated that the ore-bearing solutions are referable to deep-seated and hidden intrusive bodies. A detailed exposition of this fact will be presented in connection with the completed study (now in preparation) of the manto type of ore deposit, hence the evidence will be only indicated here.

The structural form of the mountain ranges with which these ore deposits are associated—arched fault blocks—suggests that they owe their origin to the intrusion of masses of igneous rock. At the Sierra del Fraile, S. L. P., two such plugs are exposed on the faulted side of the range in such a manner as to strongly indicate that they have been responsible for the uplift of the range. In other plateau ranges such an origin is suggested but is less evident.

Although granitic intrusives are nowhere in evidence at or near the Los Lamentos manto deposits, there are lamprophyric and aplitic dikes closely associated in other districts (as at Santa Eulalia and Mapimi). These must be referable to some nearby larger intrusive mass. At Mapimi deep diamond drilling has, in fact, encountered underlying granitic rock. At this locality, too, contact silicates were occasionally encountered in the deepest levels. At Naica, not only contact silicates but fluorite is developed in fair abundance in the vicinity of an aplite dike.

The striking restriction of the Los Lamentos ore pipe to the Los Lamentos limestone has given rise to much discussion concerning the question of favorable beds. It has been suggested that the favorability of the beds is due to some variation in their chemical composition. With this in mind, I carefully sampled the limestones of the main range, taking samples at each ten feet of elevation and aggregating these for an average sample of each formation. In the case of the Los Lamentos limestone the dolo-

mitized portions were avoided as much as possible since they are obviously definite parts of the mineralization. In the following table are given the results of the analyses of these samples.

ANALYSES OF LIMESTONES, LOS LAMENTOS, MEXICO.

W. F. Foshag, Analyst.

	Angela	Los Lamentos	San Vicente	Bufa
CaO	51.92	52.80	50.32	53.04
MgO	1.48	2.16	1.17	0.70
$(Fe, Al)_2O_3$	1.08	0.72	1.56	1.96
Ign. loss	43.24	44.18	41.94	43.98
Insol.	2.92	0.68	5.33	0.92
	100.64	100.54	100.32	100.60

Obviously the slight differences between the limestones are hardly sufficient to appreciably affect the emplacement of a very large ore pipe. Some physical property must have been the determining factor. This I believe is the heterogeneous character of the Los Lamentos limestone with its high content of large fossils of coarse calcite, in contrast with the fine and even-grained underlying Angela limestone. In the folding of the beds, it is reasonable to suppose that the heterogeneous Los Lamentos limestone became minutely brecciated—manifested in the abundance of small calcite veins—and thus allowed an easier passage for ore-bearing solutions than the other beds.

Some investigators believe the dolomite to be pre-mineral beds and that the chemical nature of these beds has determined the loci of the mantos. Even a cursory inspection of the dolomitized areas, however, leaves no doubt that they are later recrystallization and in general, concomitant in a broad way with the introduction of the primary ore minerals.

Although the relationship of the ore minerals to the dolomite is obscured by oxidation, it can be stated that in general the features noted are in accord with the deductions made by D. F. Hewett [7] in his studies on dolomitization and ore deposition.

[7] ECON. GEOL., vol. 23, 821–863, 1928.

There are abrupt changes in color, texture and porosity across thin transition zones. The increase in the amount of iron is apparently slight but real. The outcrops of pre-mineral intrusive rocks are either sparse and small or wholly wanting.

A striking feature of many of the limestone ore deposits of Mexico is the common occurrence of caves in close relation to the oxidized ore bodies. At Los Lamentos they are particularly abundant in the lower portion of the *manto*. Beneath the caves lie important bodies of ore. The loci of these caves were determined largely by the ore bodies, the oxidation of the sulphides forming incipient water courses, which were later greatly enlarged by descending waters to form channels and caves of considerable magnitude. In one of these caves the remains[8] of Pleistocene mammals were found over 1,000 feet from the adit entrance and 750 feet below the surface of the mountain side, indicating an open connection with the surface for considerable distances underground.

The writer wishes to acknowledge the courtesy of Dr. D. F. Hewett for his criticism of the manuscript and his discussion of the subject matter of the paper.

U. S. NATIONAL MUSEUM,
WASHINGTON, D. C.

[8] George F. Eaton. Vertebrate Fossils from the Mina Erupcion. Amer. Jour. Sci., 6, 229–238, 1923.

GRAPHITE DEPOSITS IN LOS ANGELES COUNTY, CALIFORNIA.

BURT BEVERLY, JR.

GEOLOGY OF THE AREA.

THE graphite deposits described in this paper occur in the "basement complex" of the San Gabriel mountains where it is more or less continuously exposed throughout the mountain area north and northeast of Los Angeles (Fig. 1).

A complex system of faults traverses the San Gabriel range, the major ones having a general east-west trend. The graphite occurs in shear zones that are intimately related to these major fault systems and form definite angles with them.

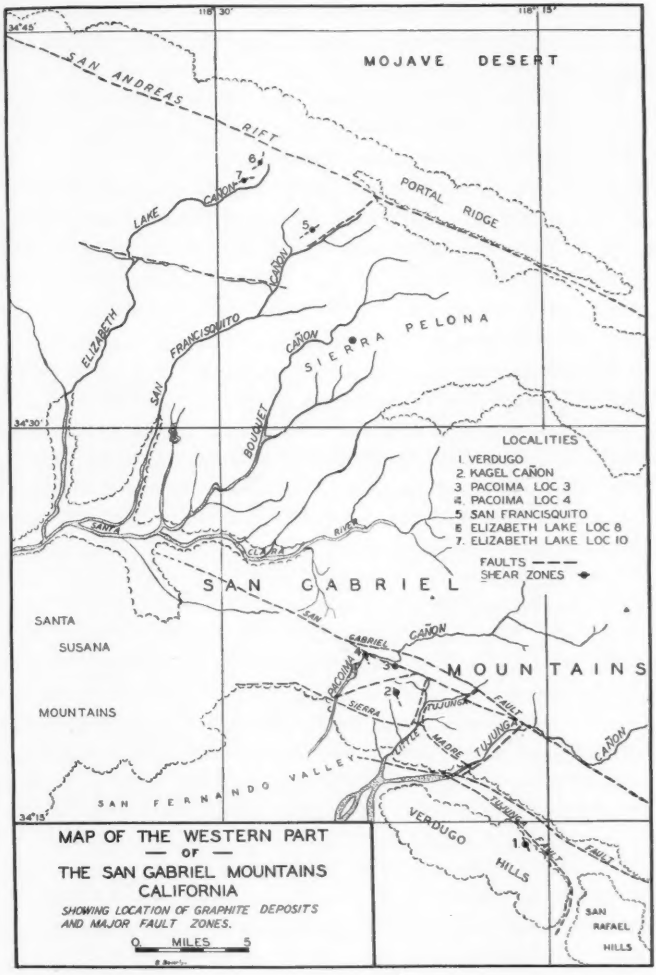
The rocks of this basement complex have never been differentiated or mapped, although Kew [1] has stated that it is made up of various types of granitic and metamorphic rocks, the latter consisting of schist, quartzite, slate and limestone, into which is intruded granite of various kinds. Arnold [2] at an earlier date studied and described some of the igneous types in more detail. Those which he found include biotite-granite, quartz-monzonite, granodiorite and hornblendite, but apparently he did not make any attempt to map their areal extent. Miller [3] has also described anorthosites.

In the present field work, the igneous rocks observed were granodiorite, granite, syenite, hornblendite and a gneiss of doubtful origin. The only metamorphic rocks of definitely sedimentary origin encountered in the areas proximate to the graphite deposits

[1] Kew, W. S. W.: Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California, U. S. Geol. Surv. Bull. 753, 1924.

[2] Arnold, R.: Some Crystalline Rocks of the San Gabriel Mountains, California. Geol. Soc. Amer. Bull., vol. 16, pp. 123–204.

[3] Miller, W. J.: Anorthosite in Los Angeles County. Jour. Geol., vol. 39, pp. 331–344, 1931.



MAP OF THE WESTERN PART
— OF —
THE SAN GABRIEL MOUNTAINS
CALIFORNIA

SHOWING LOCATION OF GRAPHITE DEPOSITS AND MAJOR FAULT ZONES.

0 MILES 5

FIG. 1. Map showing location of graphite deposits in Los Angeles County, California.

were crystalline limestone of both calcitic and dolomitic character, and some thin bands of schistose rock which are probably of similar origin.

The rocks of the shear zones in which the graphite occurs have a pronounced foliated structure due probably to shearing stresses. Hence, the use of the term schist here is not necessarily to be construed as indicating a high degree of regional metamorphism but is employed in a structural sense to designate a rock having a more or less well developed foliated structure.

GRAPHITE DEPOSITS.

Location.—The graphite deposits studied are all located in the western portion of the San Gabriel mountains, and are scattered over a belt some 40 miles in length (Fig. 1).

No. 1 is located on the north slopes of the Verdugo Hills, which form a small isolated mass lying to the southwest of the San Gabriel range but geologically related to it.

In the San Fernando area, one deposit occurs in Kagel Canyon (No. 2, Fig. 1), and two others were found in Pacoima Canyon (Nos. 3 and 4, Fig. 1).

A fifth (No. 5, Fig. 1) is located on the western slope of San Francisquito Canyon, near its head. The last two (Nos. 6 and 7, Fig. 1) occur in the upper part of Elizabeth Lake Canyon, near its junction with the San Andreas Rift Valley.

Geologic Relations.—The shear zones in which all the graphite deposits occur are, in most cases, traceable for distances of from 2000 to 4000 ft., and are of variable width, ranging from a minimum of 5 or 6 ft. up to a maximum of 100 feet in the case of the San Francisquito and Pacoima Canyon deposits.

The rocks bordering the shear zones may be granite, granodiorite, or gneiss; commonly, different rocks are on opposite sides. An exception to this is the Elizabeth Lake Canyon deposit (No. 7), where the shear zone abandons the contact and passes into the granodiorite. So far as observed, the wall rocks where unsheared are lacking in graphite.

Pegmatite is everywhere associated with the graphite; in most

places it is strongly sheared. Associated with it are schistose rocks such as biotite schist, graphite schist, graphite-quartz-biotite schists, and in one case each serpentine, and crystalline limestone.

Several localities deserve detailed mention.

San Francisquito Canyon.—The shear zone contains much sheared pegmatite, with biotite and graphite schist. The graphite occurs as bands or stringers in the pegmatite, and also as flakes in the biotite schist; the flakes penetrate both the feldspar and biotite (Fig. 2). Serpentine is also present in small amounts. Portions of the graphite schist contain long prisms of sillimanite, and the graphite flakes lie parallel to them and also cut across them.

Kagel Canyon.—(No. 2, Fig. 1.) A section across the shear zone at one point shows: banded gneiss wall rock, serpentine marble, quartz-biotite-serpentine, and sillimanite schists, graphitic pegmatite and granodiorite wall rock. The graphitic pegmatite is strongly sheared and resembles a graphitic schist.

About 500 feet farther along the shear zone, the serpentine marble is lacking and the central part of the zone is occupied by a band of biotite schist, which except for the presence of garnet has the same composition as the gneiss wall rock on the east, and possibly represents a sheared phase of the latter. The schist is flanked on both sides by graphitic pegmatite, which in spots contains a large amount of sillimanite.

The graphite occurs: (*a*) most abundantly as small flakes in lenses and stringers of sheared pegmatite; (*b*) as disseminations in a sillimanite schist impregnated with pegmatitic material; and (*c*) irregularly distributed in the quartz-biotite-serpentine schist which is in all probability a hydrothermally altered phase of the serpentine marble.

Some of these rocks may be in part metamorphosed sediments as represented by the serpentine marble and the sillimanite schists, but it is significant that the graphite is most abundant in the pegmatite, and in portions of the sheared rocks injected by it.

Farther down the canyon there is a large outcrop of dolomitic

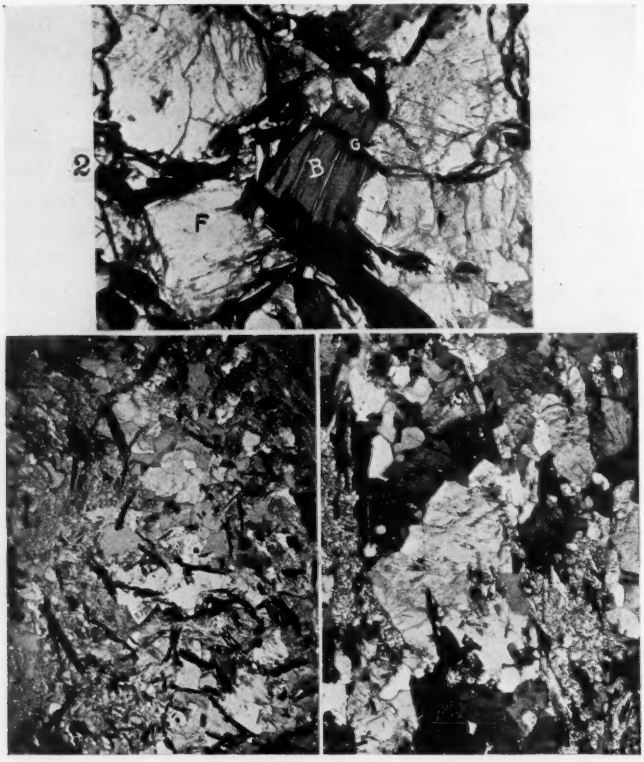


FIG. 2. Biotite schist, San Francisquito Canyon. *F*, feldspar; *B*, biotite; *G*, graphite. Plain light, × 35.

FIG. 3. Graphite schist, Elizabeth Lake Canyon. From central part of shear zone. Crossed nicols, × 17.

FIG. 4. Sheared and altered granodiorite from shear zone, Elizabeth Lake Canyon. *S*, sillimanite; black, graphite. Polarized light, × 35.

marble which contains no graphite. The serpentine marble mentioned above is probably an altered phase of it.

Pacoima Canyon.—(No. 3, Fig. 1.) One occurrence shows pegmatite, composed chiefly of orthoclase and quartz, with flakes of graphite scattered through it.

The mineral grains have been fractured, and the borders of the feldspar replaced by a myrmekitic intergrowth, which locally may be of some extent. The graphite has been deposited along cleavage cracks, fracture zones, and in the myrmekitic borders; it has also replaced the feldspar as a spray of little flakes, which in many instances are separated from the feldspar by narrow borders of sericite.

In addition to the graphitic pegmatite there are a few areas of graphite schist consisting predominantly of quartz, andesine and graphite. This has a highly cataclastic structure, and the quartz has been completely recrystallized in places. The graphite replaces both the quartz and feldspar.

Half a mile farther down the canyon, the shear zone is made up chiefly of biotite schist with pegmatite in dikes, stringers and lenses. The graphite flakes occur in both rocks, although unevenly distributed. Their outlines are very irregular; projections extend into the feldspar, and between the leaves of biotite, but their somewhat regular distribution in parts of the biotite schist suggests the possibility that this rock is a metamorphosed carbonaceous sediment. In either case, the graphite seems to have developed later than the biotite or feldspar.

Elizabeth Lake Canyon.—There are two graphite deposits in the upper part of this canyon, near its junction with the San Andreas rift valley.

In the more northern one (No. 6, Fig. 1) the graphite first appears as a vein about 15 inches thick between walls of crushed granodiorite. To the southward, the shear zone widens out to 50 feet and consists of stringers and dikes of graphitic pegmatite with lenses of biotite-sillimanite schist and fragments of the granodiorite wall rock. The biotite schist is composed of orthoclase, quartz, biotite, sillimanite, muscovite, beidellite and graph-

ite. The sillimanite prisms in general occupy shear fractures, but may penetrate the quartz and feldspar. The graphite forms elongated flakes that penetrate the feldspar and fills spaces between biotite and sillimanite grains; it appears to have formed later than these three minerals. The beidellite forms patches and also fills fractures in the feldspar, but is probably later than the graphite. It may be of hydrothermal origin.

Still farther south along the shear zone is a band of graphitic schist, ten feet wide, which can be traced for 1000 feet. This rock is a sheared mixture of orthoclase, quartz and graphite, with a few prisms of sillimanite in the shear fractures, or in the crushed matrix (Fig. 3).

About 2½ miles farther down the canyon there is another deposit, in which the central part of the shear zone is formed of a schistose quartz-feldspar rock, with local enrichments of biotite and sillimanite, as well as numerous small flakes of graphite. At one point there is a small mass of rock composed of tremolite which has been partly replaced by talc, and the latter in turn by graphite. Its original character is unknown.

Bordering the central zone is a light colored crystalline rock, having essentially the same mineral composition and texture as the granodiorite wall rock, but differing from it in showing only remnants of altered biotite. Slender prisms of sillimanite occupy the fractures, and flakes of later graphite replace the feldspars (Fig. 4).

ORIGIN OF THE GRAPHITE DEPOSITS.

From the foregoing descriptions it is clear that the graphite is mostly confined to the central portions of the shear zones, in which the rocks, except portions of the pegmatites, always show a well developed schistosity. This structure is due to shearing stresses and rarely extends into the wall rocks.

Two theories may be suggested to explain the shear zones and the graphite in them:

(1) Their formation may have been controlled by the presence of narrow bands of metamorphosed sediments, and the carbon may be regarded as an original constituent of these. A modifica-

tion of this theory would assume sheared bands of meta-sediments into which the graphite has been introduced.

(2) They may have been developed irrespective of the physical character of the country rock, and the graphite may have been introduced by hydrothermal processes.

Each of these may be briefly discussed.

Theory 1.—Metamorphosed sediments are known to occur in the basement complex of the San Gabriel Mountains, and might present an easy path of relief for shearing stresses set up in the basement complex. The rocks of the shear zones have been so strongly sheared and crushed that their original character and structure has, in most places, been obliterated. An exception is the serpentine marble of the Kagel Canyon deposit, and possibly some of the biotite-sillimanite schists previously noted. Some sediments were, therefore, present, but the evidence is equally convincing that not all the rocks of the shear zones were originally sediments. The mere presence of graphite in a rock is not necessarily proof of its sedimentary origin, since it may have been introduced at a later date.

There is not much to support the first theory.

Theory 2.—As already pointed out, the basement complex of this region contains large areas of igneous rocks[3a] several of which form the wall rocks of the graphite-bearing shear zones. It has also been pointed out that the rocks of the shear zones are in some cases wholly or in part sheared phases of the igneous wall rock. Pegmatite is also present in all the graphite-bearing shear zones, and is itself in places badly sheared. These facts tend to show that these zones were not controlled by beds of meta-sediments.

The evidence which points to an introduction of the graphite is: (1) It occurs most abundantly in the central portion of the shear zones near the pegmatite bodies. (2) Graphite replaces most of all the other minerals with which it comes in contact. (3) In one case the graphite forms a narrow seam, 15 inches thick, in crushed granodiorite. Some narrow veins are also found

[3a] See references to Kew, Arnold and Miller previously cited.

in what appears to be a crushed granitic rock in the southwestern part of the San Rafael Hills near Pasadena. (4) The graphite is irregularly distributed through the schistose rocks, and may occur commonly in the pegmatite. (5) Zones of myrmekite commonly carry graphite, which replaces them. (6) The dolomitic marble outside the shear zone contains no graphite, but the highly altered marble close to it does. (7) Graphite has been developed in crushed zones in minerals, and penetrates the individual grains, which clearly indicates its later age.

Relation of the Graphite to Fault Zones.—All the graphite deposits are intimately related to the fault pattern of the region, the shear zones being apparently subsidiary shear fractures of the major fault zones. These fractures would offer easy channelways for the ascending hydrothermal solutions which have altered the rocks and deposited the graphite.

The attitude of these shear zones is in every instance vertical or steeply dipping, and there is evidence that the movement on the major fault, to which they are related, must have been strike-slip in part.

Nature of the Solutions.—Nothing definite can be said regarding the nature of the graphite-bearing solutions, since up to the present no physical-chemical evidence has been offered to indicate what the actual composition of such solutions might be. The common and close association of the graphite with sericite might suggest that they were alkaline. The universal association of graphite with pegmatite strongly indicates that the two came from a common source. Because of the tendency of the graphite to replace the other minerals, it may represent an end-stage reaction.

Source of the Graphite.—So far as is known at present, none of the recognized meta-sediments away from the shear zones contain any graphite. This leaves two possible sources: (1) That the graphite is of magmatic origin, which the author does not consider impossible, or (2) that the rising solutions associated with the pegmatite brought the carbon from some underlying sediments.

Whatever the source of the graphite, the evidence seems fairly conclusive that a large part of it has been transported to its present position in the shear zones, notwithstanding the fact that

some of the schist, as in Kagel Canyon, may be a meta-sediment.

Source of the Sillimanite.—If some of the biotite-sillimanite schist found in one of the Kagel Canyon deposits is a meta-sediment, the occurrence of the sillimanite in it presents no problem. But the sillimanite found in the pegmatite, as a filling of fracture zones in some of the schists, and in one case at least, in the sheared granodiorite, is of particular interest. In these instances it may have come from the same source as the graphite.

Sillimanite has been noted in pegmatites from Virginia,[4] and in Idaho,[5] where a magmatic origin has been assigned to it.

SUMMARY.

The sequence of events which has resulted in the origin of the graphite deposits is thought to be as follows:

As a result of stresses set up in the basement complex by movement along major fault zones, subsidiary shear zones have been formed. The latter have developed irrespective of the character of the country rock; both igneous and metamorphic rocks, the latter predominating, have been affected.

During the shearing, or alternating with it, there has been introduction of pegmatitic material, as well as some hydrothermal alteration of the sheared rocks. Mineral changes taking place during the latter period were, serpentinization of the dolomitic marble, alteration of the hornblende of some of the granodiorite to biotite, and formation of the tremolite. Reactions forming the sillimanite probably also took place at this time. At a later stage of the activity, graphite was introduced. Following this, movements along the shear zones have further crushed the rocks, and produced slicken-sided surfaces on the graphite.

The writer wishes to express his appreciation for helpful suggestions received from members of the Geological faculty at Cornell University.

CORNELL UNIVERSITY,
ITHACA, N. Y.

[4] Pegau, A. A.: Pegmatite Deposits of Virginia. Va. Geol. Surv., Bull. 33, 1932.

[5] Anderson, A. L.: Genesis of the Silver Hill Tin Deposits. Jour. Geol., vol. 36, p. 646, 1928.

"PEBBLE DIKES" AND ASSOCIATED MINERALIZATION AT TINTIC, UTAH.

ROLLIN FARMIN.

INTRODUCTION.

THE Tintic mining district, Utah, is located in the East Tintic range, about 60 miles due south from Salt Lake City. Since the first discovery, in 1869, the mines of the district have produced ores of gold, silver, copper, lead and zinc valued at approximately $340,000,000 and have paid about $52,000,000 in dividends.

Among the many interesting geologic features of the district are the "pebble dikes" and this paper will be devoted chiefly to description of them and to interpretation of the character and associations observed in them by the writer.

"Pebble dikes" have been recognized in the district for at least 20 years and several incidental descriptions of them have been written.[1] They have also been recognized[2] at Bingham, Park City, Stockton and Jordan Narrows, in Utah, and at Aspen, Ouray, Cananea, and probably many other localities, where some may have been described under different names, such as "breccia pipes."

Among the first to observe the "dikes" at Tintic was G. W. Crane, who interpreted them as "shore-line gravels filling fissures." Another interpretation of "pebble dikes" advanced in discussions is that the pebbles are friction breccia developed between fault walls. Billingsley, Parsons and Smith recognized a hypogene origin of the "dikes," whereby pebbles were broken

[1] Parsons, A. B.: The Tintic Standard Mine. E. and M. Jour., vol. 120, no. 17, p. 646, 1925. Crane, G. W.: Notes on the Geology of East Tintic. A. I. M. E. Trans. Preprint 1491, 6–7, 1925. Smith, Norman: unpublished manuscript. Billingsley, Paul: Tintic Mining District. 16th Int. Geol. Congress Guidebook 17, p. 117, 1933.

[2] The writer has not seen some of these occurrences.

from formations at depths of hundreds of feet or more, and were carried upward to their present positions by either steam, gas, solutions or muds, in response to the pressure of intruding magma. The latter is the prevailing concept at present and the conclusions in this paper are in general accord with it.

Acknowledgments.—The writer is greatly indebted to Professor B. S. Butler for constructive criticism, both of the problem and the manuscript, and to Mr. John M. Boutwell for further assistance in preparation of the manuscript. Messrs. Reno H. Sales and Tom Lyon, as well as field associates of the writer in International Smelting Company, have given helpful discussions of the problem.

GENERAL GEOLOGY OF TINTIC.

Sedimentary Rocks.—The oldest formation in the district is the Lower Cambrian Tintic quartzite, of which a 3,500-foot thickness [3] is exposed, with a 125-foot conglomerate bed at its base that probably marks the bottom of the Cambrian. Overlying the Tintic quartzite is a series (Fig. 1) of shaly limestones and dolomites, 6,700 feet in thickness, ranging in age from Middle Cambrian to Upper Mississippian.

Igneous Rocks.—Stocks, which range in composition from monzonite to rhyolite porphyries, occupy considerable areas of the district. Dikes of similar igneous rocks have been sparingly intruded into the areas of sedimentary formations, and equivalent volcanic rocks have been extruded over much of the remaining surface. The igneous rocks are of post-Early Eocene age.

Structure.—Folding and associated compressional faulting strongly deformed the sedimentary rocks at some time [4] later

[3] Lindgren, Waldemar and Loughlin, G. F.: Geology and Ore Deposits of the Tintic Mining District, Utah. U. S. Geol. Survey Prof. Paper 107, p. 22, 1919. Loughlin gives the thickness of the formation as 6,000 + feet; since then a fault has been recognized by the writer which partly duplicates the formation in its type section.

[4] Loughlin, G. F.: *Op. cit.*, p. 103. Also Butler, B. S. and others: The Ore Deposits of Utah. U. S. Geol. Survey Prof. Paper 111, 102–103, 1920. Loughlin places the date of folding at the close of Jurassic or early in Cretaceous time. Butler dates the folding as post-Cretaceous or early in Tertiary time.

AGE	FORMATION		THICKNESS
U. Mississippian	Humbug	Sandstone and Limestone	224 feet
L. Mississippian	Pine Canyon	Humbug Limestone	397
		Tetro Limestone	335
	Gardner	Black Carbonaceous Shale	160
		Gray Fossiliferous Dolomite	160
		Blue Fossiliferous Limestone	90
		Sugary Dolomite	80
		Black Dolomite	64
		Blue Shaly Limestone	38
		White Limestone	31
		Blue Flaky Limestone	120
		Mottled Dolomite	
	Victoria	Ashy Gray Dolomite & Quartzite	209
U. Ordovician	Blue Bell	Noah Dolomite	290
		Dora Dolomite	212
		Beecher Dolomite	212
		Eagle Dolomite	180
L. Ordovician	Opohonga	Shaly Limestone	857
	Ajax	Upper Ajax Dolomite	390
		Emerald Dolomite	30
		Lower Ajax Dolomite	205
U. Cambrian	Opex	Upper Opex Shaly Dolomite	295
		Lower Opex Dolomite	215
Middle Cambrian	Cole Canyon	Dolomite	600
	Blue Bird	Dolomite	189
	Herkimer	Shaly Dolomitic Limestone	270
	Dagmar	Dolomitic Limestone	79
	Teutonic	Limestone	420
	Ophir	Shale, Limestone & Quartzite	358
			6782
Lower Cambrian	Tintic	Quartzite	3500
			Tot. 10282

FIG. 1. Stratigraphic section, Tintic District, Utah. After G. W. Crane.

than Carboniferous. The major structure developed in them is a synclinal fold, broken by transverse faulting and by complex minor folds (Fig. 2). Subsequent uplift and erosion developed a topography of strong relief in the sedimentary rocks before they were intruded, in post-Early Eocene time, by the magmas which formed the stocks, dikes, and volcanics. A late factor in the igneous activity was injection of "pebble dikes" and mineralizing solutions into the freshly faulted and fissured rocks. Since mineralization, there has been some faulting of the Basin-

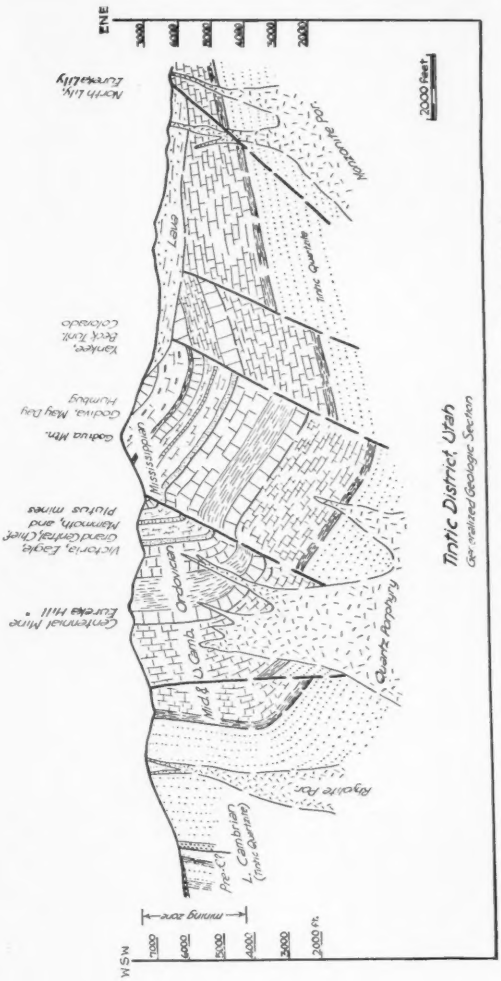


FIG. 2. Generalized geologic structure section, Tintic district.

Range type and erosion has stripped the lava capping from part of the area.

DESCRIPTION OF " PEBBLE DIKES."

Definition.—A " pebble dike " is a vein-like mass composed of well-rounded to sub-angular pebbles of materials corresponding to formations of the district, several of which are usually represented, in a matrix that is generally a carbonate mud of finely broken limestone fragments, but that also may be a jasperoidal gangue or an intrusive igneous rock. Pipe-shaped masses of similar materials are included in the term " pebble dike."

Character of Pebbles.—Pebbles derived from the Tintic quartzite are most abundant, and are easily recognized in the " dikes " because of their white to pink color and their even grain, whereas the almost equally abundant pebbles of limestone, dolomite and shale are less diagnostic. Pebbles of porphyry have been found in " dikes " a thousand feet from any known porphyry masses but are more abundant in " dikes " near intrusives. In general, porphyry pebbles are less common than are the pebbles from sedimentary formations. Pebbles range in size from 1/10 to 15 inches in diameter and many of them are smoothly rounded to a roughly spherical form, as are stream-worn pebbles. Quartzite pebbles are the ones most rounded. Many of the quartzite pebbles exhibit an " onion " structure of concentric shells, each shell separated from the adjoining one by a minute curved parting, which may not be easily visible until the pebble is broken for examination. No cement between shells has been observed, and thin sections show only a clean fracture separating them. The structure is confined to the outer portion of the pebbles and rarely extends one-half inch inward from their surfaces.

Porphyry pebbles also are well-rounded except in " dikes " near igneous intrusives, where many are markedly angular and some are unusually large, several feet in diameter. Pebbles in " dikes " occurring far above the formations of their derivation are mostly much smaller in diameter than are pebbles nearby their corresponding formations.

Character of Matrix.—The matrix surrounding the pebbles

differs in the several types of "pebble dikes." In association with igneous dikes, the matrix is fine-grained porphyry and equals the included pebbles in volume. In a second type of "dike," the matrix is dark-colored jasperoid, either chalcedony or microcrystalline quartz, and is of much greater volume than are the included pebbles. In a third, and most common type of "pebble dike," the matrix is of small volume and is composed of a carbonate mud of finely broken fragments of the pebbles themselves.

Character of the "Dikes."—The deposits of pebbles are mostly tabular in shape, as is suggested by the term "dike." Likewise, "pebble dikes" resemble veins, as both commonly occupy lenses in those northeasterly-trending fissures so commonly mineralized at Tintic. The fissures are filled with "pebble dike" material from one-half inch to several feet in width and for lengths up to 400 feet and depths up to 200 feet; some may be of greater depth. Many "dikes" do not extend to the surface. "Pebble sills" branching out from the main "dike" are not uncommon. Some attain a width of several feet and length of thirty feet, although small ones of an inch or two in width are more common.

The "pebble dikes" also occur as pipes, roughly elliptical in cross section, and as large mushroom-shaped masses up to two hundred feet in diameter. In them the proportion of large angular fragments is greater than in the lenticular type, but many perfectly rounded pebbles are also present, some of which exhibit "onion" structure.

Distribution.—The "dikes" are most abundant along the Godiva and Iron Blossom ore channels. They are also common in the neighborhood of the Central Standard, Baltimore, North Lily and Tintic Standard properties, on the east side of the district. "Pebble dikes" have been found less abundantly in other parts of the district: they seem to be more common in areas near igneous dikes and near large jasperoid masses.

Most of the "dikes" are found in a sedimentary country rock, although on the east side of the district many penetrate a lava capping above the sedimentaries. They are uncommon, if not

lacking, in the igneous stocks and in the thicker volcanic rocks.

Association of Mineralization with "Pebble Dikes."—An important feature of "pebble dikes" is the close association of a few of them with ore bodies and with lean masses of iron- and manganese-stained jasperoid. Three general types of association are recognized:

In the Plutus mine (1,300 to 1,500-foot levels) typical lenticular "pebble dikes" containing pebbles of limestone, shale, porphyry and Tintic quartzite are intimately associated with

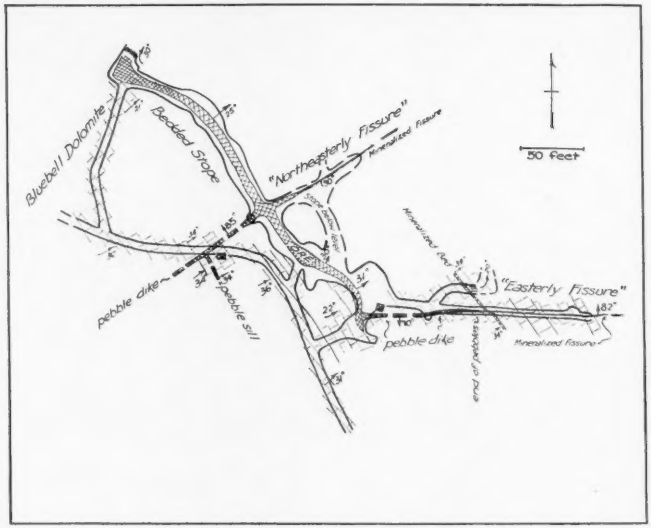


FIG. 3. Horizontal section, 1,500-foot level of Plutus mine.

bodies of rich silver-lead ore. Fig. 3 is a map of a portion of a bedded ore body from which two "pebble dikes" extend. One of them fills the "Easterly Fissure" from the point where it leaves the hanging wall of the ore body and extends, with diminishing width, to a point 85 feet distant, beyond which only carbonate vein material fills the fissure. The "Northeasterly

Fissure" (Fig. 3) is filled with "pebble dike" material on the footwall side of the ore body but is filled with low grade ore on the hanging wall side.

A second type of association is found in the large pipes, some of which have an igneous matrix. Masses of jasperoid are present in them, and ore bodies have been found along their margins and extending outward and upward from them. Examples of this type are found in the Eureka Hill and Mammoth mines.

A third type of association is in the iron- and manganese-stained jasperoid reefs, which occur as short, thick veins and as

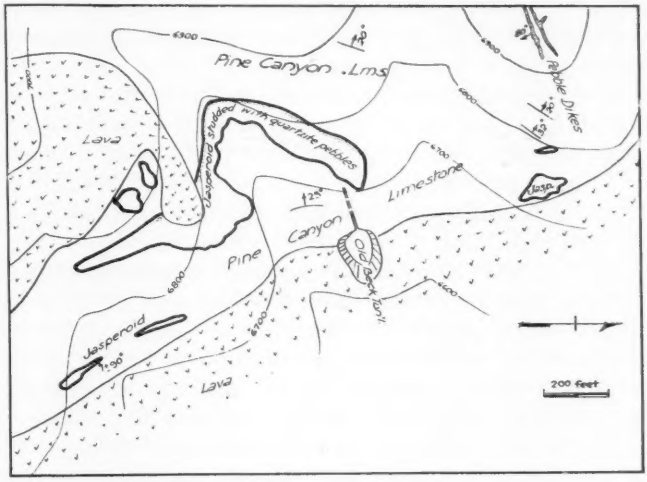


FIG. 4. Areal geology near Old Beck Tunnel, Tintic, Utah.

large irregular masses. The most striking association of this type is in the large jasperoidal mass near the portal of the Old Beck Tunnel (Fig. 4). Its flat-dipping upper surface forms a bold out-crop that follows the contours of the topography into the gulches and out around the ridges, for a distance of 1,000 feet. Much of the upper margin of the jasperoid is thickly studded with

pebbles of Tintic quartzite, some exhibiting "onion" structure. The occurrence is in the upper Pine Canyon formation, 6,000 feet above the Tintic quartzite.

INTERPRETATION OF OBSERVATIONS.

Origin.—Several explanations of the origin of the "dikes" have been advanced by earlier writers. That of supergene filling of open fissures with Lake Bonneville gravels is here rejected because many of the "dikes" crop out at elevations 2,000 to 3,000 feet higher than the lake beds in question; also, many of the "dikes" do not extend to the surface; some are more than 1,000 feet below it at their highest points. Origin of the "dikes" as friction breccias due to faulting is likewise not acceptable because many "dikes" transect limestone marker beds without offsetting them more than an inch or two, although the pebbles in the "dikes" are derived from formations that lie as much as 6,000 feet below the inclosing wall rocks. Moreover, "pebble sills" extend out normal to the main "dikes," and such "sills" could not be explained satisfactorily by movements parallel to the "dikes." Action of geysers and hot springs did not form the "dikes" because there is none of the expectable crustified deposit of carbonate or silica between pebbles; also, a hot spring deposit has been found (on the summit of Godiva Mountain) that transects a "pebble dike," with travertine coatings deposited in cracks between broken masses of "pebble dike" material, showing the travertine to be much younger than the "dike."

The origin of "pebble dikes" here accepted is: fragments were broken from underlying rocks by magma, or by fluids ejected from the magma during volcanism, and were forced upward into the rocks in which they are now found in a relatively thick mud, which was deposited, with its load of pebbles, when the pressure on the fluid from the parent magma became weakened, or when the fluid escaped to the surface as a gas through opened cracks. In a few of the "dikes" the matrix surrounding the pebbles is porphyry and the "pebble dike" material gives way immediately below to true igneous dikes. "Pebble dikes" of this type are

clearly of intrusive origin, in which pebbles of brecciated country rock were carried along by the advancing front of the intruding magma.

Many of the "dikes," however, are not closely connected with igneous bodies and have only a small amount of matrix, a carbonate mud composed of finely broken limestone fragments. These are the typical "pebble dikes," mostly lenticular in shape, with limited vertical and horizontal range. Some of the pebbles in them have been carried upward several thousand feet from their nearest possible source and during that journey the stream of pebbles was very mobile, as indicated by the tiny "sills" that extend out into the wall rock from the main body of pebbles. This suggests that some fluid medium, such as a magmatic solution, gas or mud, enveloped the pebbles and facilitated their transport, in lieu of the igneous matrix in the other type of "pebble dike." It seems doubtful that the pebbles would have migrated far and have been deposited in the form of "dikes" and "sills" if the stream of pebbles was "dry" during its injection, with the pressure that caused the intrusion transmitted wholly by the thrust of each pebble against its neighbors. The probability of a fluid medium is further strengthened by the apparent lack of pebble-filled roots beneath some of the "dikes," which suggests that the charge of pebbles may have been transported through considerable lengths of conduit, far in advance of the intruding magma, without deposition of any pebbles until a release of pressure was effected. From the several abovementioned fluid media, an aqueous mud heavily loaded with pebbles is here favored because pebbles in the "dikes" are not encrusted in carbonate, such as would result from a long continued flow of dilute heated solutions, nor are they accompanied by deposits of the minerals commonly associated with volcanic gases. The noncommittal term "fluid" is preferred to one designating phase, such as "gas" or "liquid," because under the wide range of pressures involved, the fluid might change from a liquid to a gas or *vice versa*.

The pebbles were injected into the country rock under a physical

pressure capable of forcing apart the walls of the invaded ground wherever that was necessary to open a channel for the pebbles. Alternative methods of injection are rejected because: (1) open fissures probably did not exist in some of the rocks invaded, such as closely folded shales and compressional fault zones; (2) chemical replacement of the invaded rocks by solid pebbles is not feasible; (3) the fluid medium that transported the pebbles could not have dissolved and removed, with equal efficiency, rocks of such diverse composition as the transected beds of quartzite, shale, limestone, dolomite and lava in order to make room for deposition of the pebbles.

Source of the Pebbles and Matrix.—Tintic quartzite pebbles are more abundant than others in the " dikes " because the Tintic formation is nearly as thick as all other sediments combined and was nowhere entirely removed by erosion at the time of injection, thus offering the greatest volume of rock from which fragments could be collected. Moreover, quartzite pebbles are best able to withstand chemical and mechanical attack during transport. The sources of several kinds of pebbles found in the " pebble dikes " can be accurately fixed by determining the local depth of the formation from which the pebbles were derived. For example, certain " pebble dikes " in the eastern part of the district occur between walls of Tintic quartzite, and the pebbles comprising them are composed of the same quartzite. The source of the pebbles may be nearby and is limited, at most, to the 3,500-foot thickness of the formation. Much greater transportation is found in " pebble dikes " on Godiva Mountain, in which pebbles of Tintic quartzite have been forced up through more than 6,000 feet of carbonate sediments, and through an unknown part of the Tintic formation itself. But limestone pebbles in the same " dikes " are from successively higher formations; thus, in a given " dike," the range in depth of source of the pebbles is from a few feet to more than 6,000 feet.

The matrices between pebbles are igneous rock, jasperoid, and a carbonate mud of finely broken fragments of limestone, dolomite, shale, quartzite and porphyry. The source of the igneous

matrix was in the masses of magma underlying the Tintic area, which also supplied the material for the igneous dikes intruded at the close of the period of volcanism. The source of the jasperoidal matrix was probably in colloidal silica collected in, or marginal to, the same magmas. The source of the materials in the carbonate matrix is the same as the source of the pebbles—they were broken from the transected formations by the invading stream of fluid and pebbles.

Origin and Significance of "Onion" Structure in Pebbles.—The rounding of the pebbles during transport was accomplished principally by corrasion between pebbles and between pebbles and walls. The "onion" structure developed in some of the quartzite pebbles, and less commonly in limestone pebbles, is not easily interpreted, although the understanding of it would furnish a valuable source of information about the physical environment of the pebbles during their injection.

"Onion" structure was developed before the pebbles came to rest, because segments peeled from their outer shells are not to be found in the encircling matrix. An apparent origin of the structure is in exfoliation of the pebbles due to sudden initial heating at their source. This theory is not acceptable because "onion" structure—which is limited to the outer part of pebbles—is exhibited not only by large pebbles, which have been transported a relatively short distance from their source, but also by pebbles that have been transported 6,000 feet or more and worn to very small diameters during the journey. "Onion" structure developed in a pebble at its source would have been removed by abrasion during its transport. Experiments in which rounded quartzite pebbles are heated and then quenched indicate that the structure is not produced by thermal changes alone. No better explanations of it have occurred to the writer.

Even with the present limited understanding, "onion" structure is a useful criterion which identifies those pebbles exhibiting it as being of "pebble dike" origin. For example, Tintic quartzite pebbles are abundant in the pre-volcanic river gravels of the district that are often sufficiently cemented, mineralized and iso-

lated by faulting to resemble "pebble dikes;" the total lack of "onion" structure in the river pebbles helps to distinguish them from the pebbles belonging to the "dikes."

Interpretation of Association of Mineralization with "Pebble Dikes."—The close association of a few ore bodies with "pebble dikes" and the common presence of pebbles of Tintic quartzite in jasperoid reefs leads to the conclusion that some of the "pebble dikes" entered the country rock through the channels used by the mineralizing solutions and that both entered at nearly, if not quite, the same time. The occurrence shown in Fig. 3 does not lend itself to any other interpretation than that of practically simultaneous entrance of mineralizing solutions and pebbles, the pebbles riding in the advancing front of invading solutions.

A conclusion was reached earlier that the pebbles were transported in a relatively thick pulp, rendered mobile by strong pressure and that they were injected into the country rock in a comparatively short time. More or less similar traits are here inferred to have characterized those mineralizing solutions associated with "pebble dikes," although this interpretation does not preclude the replacement of the wall rocks by colloidal silica and ore minerals at the point of deposition, nor does it necessarily apply to all of the mineralizing solutions in the district.

The alternative view is that the quartzite pebbles in the jasperoid reefs might be unreplaced remnants of an older "pebble dike," silicified by subsequent dilute solutions following along the course of the pebbles. That, however, would fail to explain the pebbles studding the rim of the jasperoid near Old Beck Tunnel (Fig. 4) because earlier "pebble dikes" could not have spread across its 1,000 feet of widely curved outcrop. Clearly, the association of mineralizing solutions and "pebble dikes" is not coincidental. It seems more probable that the colloidal silica that formed the reefs advanced in a surge and carried the quartzite pebbles into the places they now occupy. In discussion of the Tintic jasperoid, Lindgren [5] states:—

[5] Lindgren, Waldemar: *Op. cit.*, pp. 155–156.

The replacement advanced like a wave over the country rock until the impulse was exhausted. . . . Silicification of the Tintic type is produced, not by metasomatic replacement, involving the development of crystals in solid rock, but by replacement of limestone or dolomite by colloidal silica, which immediately afterward became transformed into chalcedony or in part into granular quartz.

Gilluly[6] concludes that the similar large jasperoid masses of Mercur and Lion Hill (25 miles north of Tintic) involved the deposition of colloidal silica at remarkably high temperature, as evidenced by simultaneous deposition of tourmaline; also, that factors other than temperature are involved in determining the boundary between colloidal and crystalline precipitation of silica. The conclusions of the above writers do not oppose the present interpretation—that the silica was forcibly intruded into the limestone in response to igneous activity beneath, and that the silica transported the quartzite pebbles to the point where lessened pressure permitted the mass to come to rest and to solidify, with possible replacement of surrounding limestone supplementing the intrusive entry of the main body of the silica.

The association of mineralization with "pebble dikes" is interpreted as proof that the conduits, through which both invaded the country rock, were physical openings capable, at least for the moment, of permitting the passage of a stream of pebbles. This interpretation is opposed to the view that colloidal silica and ore materials advanced through the ground by capillary migration, involving only small cracks in the rocks, and then metasomatically replaced an equivalent volume of limestone at the locus of deposition.

Mineralization is known to be associated with only part of the "pebble dikes" at Tintic and ore has been found associated with them but rarely. The presence of "pebble dikes" in an area indicates that the underlying ground has been subjected to igneous intrusion and possibly to mineralization. An individual "dike" is not necessarily an indication of ore.

[6] Gilluly, James: Geology and Ore Deposits of the Stockton and Fairfield quadrangles, Utah. U. S. Geol. Survey Prof. Paper 173, p. 92, 1932.

CONCLUSIONS.

1. The pebbles in the Tintic "pebble dikes" were not of surficial origin, nor were they formed by faulting nor by hot springs. They were broken from underlying formations by fluids of magmatic origin and were injected upward into the country rock.

2. The depth of source of the pebbles ranges from more than 6,000 feet to only a few feet below their present position in the "dikes."

3. "Onion" structure was developed in pebbles during transport and is a criterion for distinguishing pebbles originating in "dikes."

4. Mineralizing solutions and colloidal silica were injected along with the pebbles in some "dikes" and the materials entered the limestone rapidly, as a concentrated fluid, by forcing apart the wall rocks to permit their passage.

5. "Pebble dikes" are not reliable guides to follow in prospecting for ore, although in a general way they indicate the presence of forces allied to those which produce ore.

EUREKA, UTAH.

SILVER MINERALIZATION IN THE BANNER DISTRICT, BOISE COUNTY, IDAHO.[1]

ALFRED L. ANDERSON AND ALFRED C. RASOR.[2]

INTRODUCTION.

THE Banner district in Boise County, Idaho, is an old silver camp that flourished for a time and then, like so many of the early-day bonanza camps, entered a period of decline and decay from which it has never recovered. During the height of its boom days it produced silver bullion valued at more than $2,000,000. The rich silver deposits were discovered in 1864, but most of the production came between 1882–1894, principally from the Crown Point and Banner lodes. The total production has been estimated at about $3,000,000, two-thirds of it from the Crown Point and the remainder from the Banner. Mining declined early in the present century, and there has been no production since 1921.

In spite of an early-day prominence, the district has received little geological attention. Veins have been reported as narrow, but rich in silver minerals. There has been no comprehension, however, of the complexity of the mineralization, of the fact that the ore minerals consist largely of rich silver sulphantimonides, particularly pyrargyrite and owyheeite, and that the mineralization is related to Tertiary magmas and not to the Idaho batholith in which the veins occur. These studies have also shown that the primary minerals are complexly intergrown and afford an

[1] Published by permission of the Director, U. S. Geological Survey, and the Director, Idaho Bureau of Mines and Geology.

[2] The writers wish to express their appreciation to Messrs. G. F. Loughlin and C. P. Ross of the U. S. Geological Survey for assistance in the preparation of the manuscript. The junior author, Teaching Fellow in Geology at the University of Idaho, School of Mines, assisted in the field, in the laboratory identification of the ore minerals, and in the compilation of historical data, but the senior author assumes full responsibility for the description and interpretation of the mineral relations, paragenesis, and all geological data and conclusions.

interesting paragenetic problem. In all, the Banner district contributes considerably to the knowledge of the character and genesis of the silver mineralization in the southern part of the state.

Geography.—The Banner district lies approximately 75 miles northeast of Boise, in the mountains drained by the Boise River, and lies along one of the mineralized belts that extend across part of the famed Boise Basin. It is situated on the divide between the Boise River drainage and the South Fork of the Payette River, at an elevation of about 6,000 feet. The mountains are of the dissected-plateau type and the veins outcrop on the old forested plateau surface at the head of Banner Creek, a tributary of the Boise River, near the rim of the 3,000-foot canyon of the Payette River.

GENERAL GEOLOGY.

Veins in the Banner district are accompanied by porphyry dikes and are confined to a zone of shearing far within the Idaho batholith. There are several prominent shear zones in the general region, each of which contain porphyry and other dikes, and much of the mineralization. It is customary to refer to the zones along which the younger dikes are mostly concentrated as "porphyry belts." The most prominent of these passes through the Quartzburg-Grimes Pass region in the Boise Basin and has recently been discussed by Ross [3] and earlier by Lindgren,[4] Jones,[5] and Ballard,[6] but in the belt that crosses the Banner district the dikes are not nearly so conspicuous nor so abundant.

Renewed movement along the shear zone following dike intrusion provided channels for the movement of ore solutions, for at least one of the porphyries is cut by a vein. Mineralization occurred, however, before igneous activity had entirely ceased, for

[3] Ross, C. P.: The Lode Deposits in the Boise Basin, Idaho. ECON. GEOL., vol. 28, pp. 329–343, 1933.

[4] Lindgren, Waldemar: The Mining Districts of the Idaho Basin and the Boise Ridge, Idaho. U. S. Geol. Survey, 18th Ann. Rept., Part III, pp. 617–744, 1898.

[5] Jones, E. L., Jr.: Lode Mining in the Quartzburg and Grimes Pass Porphyry Belt, Boise County, Idaho. U. S. Geol. Surv. Bull. 640-E, pp. 83–112, 1916.

[6] Ballard, S. M.: Geology and Gold Resources of Boise Basin, Boise County, Idaho. Idaho Bur. of Min. and Geol., Bull. 9, 1924.

lamprophyric dikes were intruded into the vein fissures at the close of ore deposition.

Igneous Rocks.—The rock of the Idaho batholith in the Banner district is light gray, equigranular, with an average grain size of about 5 millimeters, and has the composition of granodiorite. Typical fresh rock from the dump at the Crown Point shaft contains quartz (29%), oligoclase (50%), microcline (16%), biotite (3%), and minor amounts of muscovite, zircon, and apatite. Near the veins the rock is thoroughly sericitized.

The porphyry dikes, like those in the Boise Basin, may be classed as granophyre and rhyolite porphyry. The most calcic has the composition of quartz monzonite granophyre, and has abundant oligoclase phenocrysts about 4 millimeters in length and less numerous and somewhat smaller quartz, hornblende, and biotite grains in a granophyric groundmass composed of radiating intergrowths of quartz and orthoclase in the form of microspherulites. Phenocrysts make up about half the rock. There is considerable epidote and calcite, and a little accessory magnetite and apatite.

The rhyolite porphyries are light gray, sparsely porphyritic rocks with scattered rounded and embayed quartz grains measuring up to 2 millimeters, and fewer and smaller chalky orthoclase and oligoclase, biotite and hornblende crystals in a microcrystalline granular (in part finely granophyric) groundmass of quartz and orthoclase. There are accessory magnetite and zircon. One of these dikes is cut by the Panamint vein. Next to the vein the dike is almost completely sericitized as a result of hydrothermal alteration attending the vein formation.

An altered lamprophyre lies in the zone of fissuring occupied by the Banner vein. It swells and pinches irregularly, and, although it is considerably bleached in some places adjacent to the vein, it is not cut by the vein or mineralized. Its intrusion apparently followed shortly after vein formation and so soon after as to have been somewhat altered by the last of the thermal solutions.

Structure.—Zones of fracturing followed by the porphyry dikes

are the major features of the regional structure. They strike about N. 60° E., transverse to the trend of the Idaho batholith. The belts are parallel and are arranged more or less *en echelon*. They are rarely more than one or two miles wide, but may continue along the strike from several miles to several scores of miles. Individual dikes, however, are mostly not more than a mile or two long, and less than 100 yards wide. Most of those in the smaller belts, as in the Banner district, are not more than 50 feet wide. Recurrence of movement along these zones of major structural weakness near the end of dike intrusion apparently provided the openings that gave access to mineralizing solutions.

Shearing or fissuring in the Banner district is much like that in Boise Basin.[7] The major fractures trend about N. 80° E. and N. 55° E., and others N. 20°–60° W. The Crown Point and Panamint veins each occupy fissure zones that strike about N. 55° E.; the latter dips to the north. The Banner and Golden Gate fissures strike N. 80° E., and the former dips about 80° NW. The fissure zones are limited in width and the veins have more or less defined walls. Minor fractures parallel the Banner vein and it is likely that similar relations exist along other major fissure zones.

THE VEINS.

The veins are essentially narrow fissure fillings in granodiorite (locally rhyolite porphyry) with most of the ore in the fissure zones confined to single fractures. The Crown Point, unfortunately, is no longer accessible, but its vein, according to early reports, differed from the others in its greater size and irregularity. Its average thickness was about four feet, but ranged up to 12 feet, with the ore more or less segregated in pockets. It was mined for 1,000 feet along the strike above the lowest or 450-foot level. The Banner vein is typical of the others and, where examined by the writers in the floor of the lowest drift (585 feet below the outcrop), ranged from about four to eight inches, the same as reported in the upper levels. It has been mined for

[7] Ross, C. P.: *Op. cit.*, pp. 336–337.

625 feet along the strike. The Golden Gate vein is reported to be from three to six inches thick for at least 325 feet along its strike, but no stoping has been done. The Panamint vein is reported at two and one-half feet.

The vein filling is mostly massive or compact, but there are also open clefts lined with drusy quartz crystals. The vein on the lowest level in the Banner mine shows faint banding of metallic minerals and comb quartz, the former constituting from one-fourth to one-half of the vein matter. The ore minerals occur in a band, mostly about an inch thick, but measuring up to about six inches. Some of the ore shows a little brecciation due to recurrent movement along the fissure during mineralization, but most of it indicates little sign of concurrent or post-mineral movement.

Secondary supergene minerals are readily recognized in the ore, because such minerals are in fractures cutting through the vein and are loosely textured.

Mineralogy.

Ore for detailed study was collected in the floor of the lowest drift on the Banner vein, and from a pile at the portal of the Banner Creek crosscut, reported to be from the same drift. Specimens were also obtained from several minor veins penetrated in the deep crosscut. All contain the same list of minerals, and in about the same proportions. This ore is composed almost wholly of primary minerals. Ore characteristic of the upper levels could not be obtained. For convenience, the mineralization will be described as hypogene and supergene, and the basis for this grouping will be discussed in a later section.

Hypogene Mineralization.

The known hypogene metallic minerals in the ore include pyrargyrite, proustite, owyheeite, miargyrite, tetrahedrite, galena, sphalerite, chalcopyrite, arsenopyrite, and pyrite. Of these, the pyrargyrite and owyheeite are the only ones conspicuously abundant. Ruby silver comprises from one fourth to one half of the metallic

minerals, pyrargyrite being much more abundant than proustite. The owyheeite, miargyrite, and tetrahedrite are so similar in physical appearance that they may be safely distinguished only with the polarizing microscope. This group is generally somewhat more abundant than the ruby silver, but individual minerals are commonly less abundant, and of the three minerals owyheeite is present in greatest quantity. Other minerals are subordinate, and are rarely observed except in polished surfaces.

The non-metallic gangue minerals include quartz and calcite. Quartz is the chief vein filling; calcite is only locally abundant.

Mineral relationships are exceedingly interesting, and many complex sulphide intergrowths may be observed in polished surfaces. Much of the ore has the texture illustrated in Fig. 1, but there are many spots, as shown in Fig. 2, where the sulphides are complexly intergrown to produce eutectic-like textures. Successive replacements have furnished evidence of a distinct age sequence. These replacements have been uncontrolled by grain or crystal contacts, or by cleavage or fracture; instead, replacing veinlets, as shown in Figs. 1 and 3, advance irregularly into the host.

Quartz.—Much of the vein quartz is fairly coarse grained, especially that deposited late and forming comb and drusy quartz, but that deposited first along the walls is finer, unevenly grained, and in part essentially chalcedonic. In most places, the combs have not wholly grown together from opposite sides of the narrow veins and the spaces between crystals are occupied by sulphides. In some places, the cavities are unfilled or only partly filled.

Most of the sulphides were deposited from the middle to the end of the quartz stage, but in some of the ore the quartz continued to be deposited after the sulphides. Some of the first quartz has been replaced by the sulphides, but the coarser grained quartz is unreplaced and the sulphides lie between the quartz crystals (Fig. 1 *et al.*).

Pyrite.—Pyrite was the first of the sulphides to be deposited. Its crystals lie mainly in the finer grained quartz next to the wall and in the wall. The individuals are small and inconspicuous.

Wherever they are in contact with other sulphides they are rounded or irregularly replaced by them.

Arsenopyrite.—The arsenopyrite appears mostly as scattered crystals, but also as closely spaced crystal aggregates. Like the pyrite it tends to form well shaped crystals near the walls of the vein, but some of it occurs in sulphides (Figs. 1 and 2). Its deposition followed that of pyrite, since it invades pyrite irregularly and some of it contains pyrite inclusions. It always shows its own outline against other minerals.

There is a suggestion of some movement along parts of the veins following the deposition of the pyrite and arsenopyrite, but neither mineral is much fractured.

Sphalerite.—The sphalerite is dark gray to black, also in part brownish, and forms rather coarse, as well as very minute, grains associated with other sulphides in the more heavily metallized parts of the vein. Part of the sphalerite contains minute chalcopyrite blebs arranged along crystallographic partings (Fig. 3) and also incloses a few larger irregular grains. The larger sphalerite grains are in part replaced along fractures by tetrahedrite (Fig. 3). The only other minerals found in the fractures are pyrargyrite and galena. This pyrargyrite all contains tetrahedrite inclusions and evidently represents the nearly complete replacement of the tetrahedrite veinlets. Galena rarely penetrates the fractures for even short distances, but where it does, it too is a replacement of the tetrahedrite. Smaller sphalerite grains commonly show various degrees of replacement and cementation by tetrahedrite, galena, and the hypogene silver minerals.

Chalcopyrite.—Chalcopyrite occurs not only as minute blebs, but also as minor inclusions in tetrahedrite and owyheeite. Its position in the mineral sequence is difficult to fix because of its scarcity and the small size of its grains, but its appearance as partly replaced inclusions in the tetrahedrite and owyheeite suggests that it is older than either.

Tetrahedrite.—The tetrahedrite is not the pure antimonial variety, but contains sufficient arsenic to give a distinct garlic odor before the blowpipe and a slight arsenic sublimate on char-

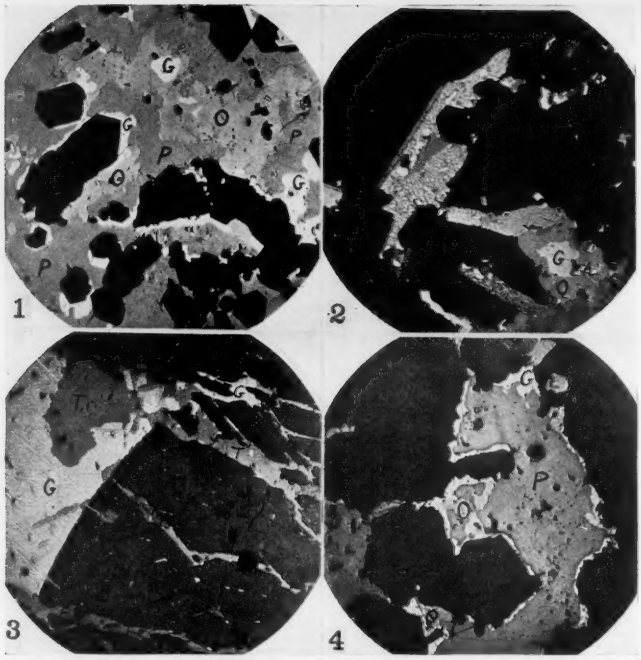


FIG. 1. Photomicrograph showing common ore texture. Galena (G) bordering quartz crystals (black) with rounded outline against owyheeite (O) and pyrargyrite (P), or inclosed in them. The galena has been largely replaced by owyheeite and pyrargyrite and the owyheeite by pyrargyrite, which has advanced irregularly into the section irrespective of crystal contacts or borders. Galena borders on the quartz have resulted from centrifugal replacement. $\times 78$.

FIG. 2. Shows pseudo-eutectic texture developed between galena and pyrargyrite. The remainder shows the more common texture developed between galena (G), owyheeite (O), pyrargyrite (P) and arsenopyrite (A). Black, quartz crystals and holes. $\times 78$.

FIG. 3. Fractured sphalerite (S) with veinlets of tetrahedrite (T), filling fractures and replacing sphalerite. Tetrahedrite outside sphalerite fractures is partly replaced by galena (G). That within is protected from replacement except in part of one veinlet. Pyrargyrite (P) is also replacing tetrahedrite along one veinlet; but is almost indistinguishable from it. The sphalerite contains some definitely arranged blebs and grains of chalcopyrite. $\times 78$.

FIG. 4. Pyrargyrite (P) showing centrifugal replacement of galena (G) representing an advanced stage, with only a narrow residual border of galena. Also owyheeite (O) remnants between pyrargyrite and galena, suggesting that the owyheeite in part or in whole first replaced the galena centrifugally, and then was replaced by pyrargyrite. $\times 78$.

coal. It replaces sphalerite along previously formed fractures, as already described, and also contains irregularly shaped inclusions (unreplaced remnants) of pyrite, arsenopyrite and chalcopyrite. The tetrahedrite, however, most commonly forms grains and irregular masses intimately associated with the silver minerals. Its relations to these minerals suggest that it was an earlier-formed mineral of which only unreplaced residuals remain.

Galena.—The galena commonly occurs either as small rounded or elliptical bodies in the silver minerals or as narrow bands between these minerals and the quartz crystals (Figs. 1 and 4). It does not vein any mineral nor has it replaced any mineral except tetrahedrite and pyrite. In a few places, the galena penetrates the tetrahedrite in the form of eutectic-like intergrowths. The penetrating galena bodies most commonly are rather widely spaced and detached parts of them appear in the plane of the section as inclusions in the tetrahedrite. Its common occurrence, however, is as rims surrounding the pyrargyrite and owyheeite grains (Figs. 1 and 4), where it has been centrifugally replaced during the hypogene silver enrichment so that only its border remains. Replacement of the galena has also produced intergrowths of the pseudo-eutectic kind (Figs. 2 and 5). Rounded and elongated grains of galena in pyrargyrite (Fig. 5), are rather common.

Owyheeite.—The owyheeite has much the same appearance as tetrahedrite in the specimen material and in polished surfaces, but it may readily be distinguished from the tetrahedrite by its lesser hardness and its strong anisotropism in polarized light. It has all the characters of the type owyheeite described by Shannon[8] at the Poorman mine in the Silver City district, Owyhee County, Idaho, and reacts for lead, silver, antimony, and sulphur in microchemical tests.[9] The formula of this rare mineral is given as $8PbS.2Ag_2S.5Sb_2S_3$. The owyheeite is apparently much more abundant than it is in the Silver City district.

The relations of the owyheeite to the galena have been partly described, but its centrifugal replacement of the galena must be

[8] Shannon, E. V.: Owyheeite. Amer. Mineralogist, vol. 6, pp. 82–83, 1921.

[9] Short, M. N.: Microscopic Determination of the Ore Minerals. U. S. Geol. Surv. Bull. 825, pp. 115–201, 1931.

re-emphasized, likewise its behavior as a host mineral for rounded galena remnants. Although it shows some tendency to form pseudo-eutectic replacement intergrowths with galena (Fig. 6), it serves much better itself as a host for the more aggressive pyrargyrite and may, in a few places, be found in pseudo-eutectic intergrowths with the replacing pyrargyrite. Its more usual form of replacement by pyrargyrite, however, is illustrated in Fig. 1. In general, the owyheeite especially attacks galena, but it also replaces earlier minerals, and rounded residual grains of tetrahedrite, chalcopyrite, and sphalerite may be found in it.

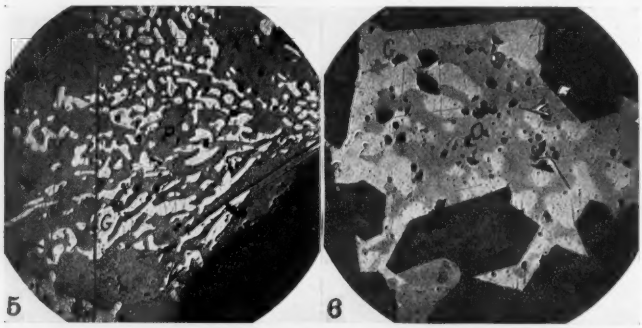


FIG. 5. A type of pseudo-eutectic texture produced by partial replacement of galena (light colored) by pyrargyrite (dark gray). ×78.

FIG. 6. Illustrating a poorly-formed pseudo-eutectic pattern produced by partial replacement of galena (*G*) by owyheeite (*O*). Note sharp crystal boundaries of quartz against sulphides, proof that quartz is not replaced by sulphides. Several small arsenopyrite crystals are in the owyheeite and quartz. ×78.

Miargyrite.—The miargyrite ($Ag_2S.Sb_2S_3$) was seen in only a few sections, and there only in contact with pyrargyrite and owyheeite. It forms irregular replacing veinlets in owyheeite, but it also assumes lath shapes in its replacement. It is in turn veined and replaced by pyrargyrite.

Pyrargyrite.—The pyrargyrite was deposited most abundantly through the interior of the ore bands, but penetrated earlier

sulphide masses to a remarkable degree and sent some replacement veinlets across the quartz into the walls. It is sufficiently abundant to give most of the ore a pronounced reddish color. It apparently contains some arsenic, for the blowpipe always produces a slight arsenic sublimate and a faint but characteristic garlic odor.

Many of its relations to other minerals have already been mentioned. Its affinity for tetrahedrite rather than for sphalerite has been discussed and illustrated (Fig. 3), likewise its penetration of galena to produce pseudo-eutectic textures (Fig. 2) and more commonly to produce centrifugal galena rims (Fig. 4). It readily attacks owyheeite and miargyrite, and it is likely that some of the centrifugal pyrargyrite, as shown in Fig. 4, is actually a replacement of owyheeite that had earlier penetrated and replaced galena. It is also common to find rounded or elliptical owyheeite bodies in the pyrargyrite, and these resemble the rounded galena grains earlier described in the pyrargyrite (Fig. 5). Eutectic-like textures between pyrargyrite and owyheeite are not infrequently seen.

Proustite.—Some proustite occurs with the pyrargyrite and appears to have ended the ruby silver deposition. It forms a few light red grains in advance of the pyrargyrite. It contains some antimony and always yields a slight antimony sublimate when heated on charcoal, at the same time giving copious arsenic fumes.

Calcite.—Calcite is everywhere late, and cements or fills in between the interstices of the quartz crystals or fills fractures in the quartz and ore minerals. In some places, the proustite projects into the calcite along cleavages for short distances as though its deposition in part overlapped that of the calcite, but most of the calcite is distinctly later and to a limited extent even penetrates and replaces the sulphides.

Gold.—No gold was observed in the ore or in the polished surfaces, but according to early reports it added appreciably to the value of the silver ore. It is said that the silver bullion contained $80 in gold to each $200 in silver.

Supergene Mineralization.

Native silver and argentite were both recognized in the ore from the bottom level of the Banner mine, but neither is abundant nor adds much to the tenor of the ore at that level. The native silver occurs as scales, flakes, or thin sheets in fractures crossing the ore, and also as fine wires twisted around quartz crystals or as wire nests in vugs. The argentite was noted only in scant amounts in several of the polished surfaces where it occurs in reticulated veinlets as a replacement along galena cleavages. It was not seen to replace any mineral except the galena, and its veinlets always end against the silver sulphantimonides and tetrahedrite. The native silver also shows replacement of other minerals in polished surfaces, but it occurs most commonly as a replacement of argentite and galena. Reasons for classing the native silver and argentite as supergene minerals will be given in the following section.

Data on secondary minerals in the upper workings are meager. According to Browne's [10] early report in 1868, the ore was prolific in horn and ruby silver, and had particles of native silver. Much cerargyrite has been mentioned by Shannon [11] in the oxidized portions of the veins and he has described argentite [12] as one of the chief ore minerals but associated with stephanite, pyrargyrite, and native silver. It is likely that the supergene silver minerals contributed a great deal to the early-day production of the camp.

HYPOGENE VERSUS SUPERGENE ORIGIN FOR THE SILVER MINERALS.

Inasmuch as some complex silver sulphosalts are known to be supergene as well as hypogene, and native silver and argentite hypogene as well as supergene, it is necessary to review the evidence, as shown in the ore and vein, by which the classification and mineral assignment as hypogene and supergene in the foregoing pages were justified.

[10] Browne, J. R.: Mineral Resources of the States and Territories West of the Rocky Mountains, p. 520. U. S. Treasury Dept., 1868.

[11] Shannon, E. V.: Minerals of Idaho. U. S. Nat. Museum Bull. 131, p. 173, 1926.

[12] *Idem*, p. 85.

One of the strongest arguments against a supergene origin for the sulphosalts is the relation of these minerals to the calcite gangue. In these, as well as in most, if not all, deposits in the Boise Basin, calcite is a late gangue mineral, and always occurs as a filling in fractures in the sulphides and early quartz gangue. The character of the country rock (all igneous) provides no adequate source for supergene calcite and the extreme shallowness [13] of the oxidized zone throughout the region affords evidence of little leaching or transportation. The calcite and its relations in the Banner district differ in no way from its occurrence in the veins in the general region, but it followed and in part overlapped on the sulphide deposition and even in part replaced the ore minerals. The silver sulphantimonides, therefore, occurred in normal succession in the hypogene sequence, which started with quartz and was completed with calcite. It is generally believed that solutions in downward enrichment would be acid and would attack the carbonates, whereas in this place the calcite actually attacks the sulphides.

The complex relations of the sulphides and sulphosalts are also suggestive of hypogene origin. The complete absence of centripetal (peripheral) replacement, (a relationship especially characteristic of supergene ores), the dominance of centrifugal replacement (a kind not described in supergene ores), and the irregular intricate replacement, independent of fracturing, cleavage, and crystal contact, all favor a hypogene origin. The pseudo-eutectic textures resulting from replacement are, according to Lindgren,[14] mainly a product of hypogene mineralization. The absence of selective replacement is also an argument against supergene origin. It is true that some of the silver minerals attack certain earlier minerals more than others, but it is also true that they replace any or all of the earlier minerals. Absence of thin coatings of these silver sulphantimonides also argues against supergene origin.

On the other hand, the evidence that the native silver and ar-

[13] Ross, C. P.: *Op. cit.*, pp. 341–342, and observations by the writers.

[14] Bastin, E. S., Graton, L. C., Lindgren, W., and others: Criteria of Age Relations of Minerals. ECON. GEOL., vol. 26, p. 606, 1931.

gentite are supergene is overwhelming. The native silver forms scales and thin plates in cracks in the fractured ore, including the calcite, and is accompanied by increased porosity. The argentite shows selective replacement of a single mineral, the galena, and its replacement is controlled by cleavage and grain contacts and develops reticulating veinlets. The native silver also occurs as a replacement of argentite and to lesser extent of galena, tetrahedrite, and the silver sulphantimonides. Further, the native silver and argentite occur only near porous or somewhat leached portions of the ore.

This discussion brings out that there is no similarity in the relations of the unquestionably supergene native silver and argentite on the one hand, and of the rich silver sulphantimonides on the other. The contrast in textural relations between the sulphantimonides and the native silver and argentite cannot allow a common origin for both. The silver sulphantimonides therefore must be hypogene and the product of progressive hypogene enrichment.

PARAGENESIS.

The silver ore shows a distinct succession of the primary minerals, all deposited, however, during a single general sequence. The succession began with the deposition of quartz, at first fine-grained and then coarser, and then, after the fissures had been half filled or more, the sulphides were deposited along with the quartz, the quartz in decreasing quantity until the very end. In some places the quartz was slightly fractured before the metallizing solutions were introduced, but along most parts of the fissures the sulphides were deposited without much interruption around and with the quartz crystals. The first sulphides deposited included minor amounts of pyrite, arsenopyrite, sphalerite, (chalcopyrite) ?, tetrahedrite, and galena in the order given, later minerals in part replacing those deposited earlier in the sequence. During part of this stage there was some movement along the fissures so that some minerals, particularly the pyrite and sphalerite, were fractured and the fractures largely filled with tetrahedrite.

The deposition of the galena was followed by the main silver metallization, during which progressive silver enrichment took place as a result of the reaction between the ascending hypogene solutions and the earlier minerals. There were deposited in normal order, owyheeite, miargyrite, pyrargyrite, and proustite, each with a corresponding increase in silver content. Deposition of each was largely by replacement of minerals earlier in the sequence. These hypogene replacements produced complex and highly interesting mineral relationships, much of the replacement of the galena having been centrifugal, and there were also formed complex intergrowths (graphic) of the silver minerals with each other and with the galena and tetrahedrite.

Primary mineralization ceased with the deposition of calcite in the remaining open spaces and in fractures induced in the ore at the close of the silver metallization.

Supergene enrichment followed later. From the scant record available in the ore at the depth where mining stopped, descending meteoric waters caused an enrichment in silver through the addition, largely by replacement, of argentite and native silver. Selective replacement occurred, since the argentite replaced galena, and the native silver replaced the galena and argentite almost to the exclusion of other minerals. Some also was deposited in cracks in the fractured ore and in drusy cavities. The record at higher levels is no longer available, and whether there was enrichment in supergene ruby silver, polybasite, etc., remains undetermined from this study.

CLASSIFICATION OF THE DEPOSITS.

Complex silver sulphantimonides are most typical of the upper vein zones, but the particular zone to which these rich silver veins belong is not easy to establish. The absence of adularia, hypogene argentite and silver or gold selenides, "colloform" banding, cellular calcite, and pseudomorphous quartz after lamellar calcite, which are features especially diagnostic of epithermal deposits, indicates that these deposits do not belong in the main part of that zone or to its upper part. Comb and drusy quartz, although

commonly abundant in the epithermal deposits, are by no means diagnostic, but are abundantly developed in many mesothermal veins. Sericitization likewise is most generally an accompaniment of mesothermal mineralization.

The character of the Banner metallization suggests epithermal mineralization, but the character of the gangue and the texture of the ore suggests mesothermal, or the cooler end of the mesothermal zone. The deposits therefore might well be assigned to the leptothermal,[15] a zone whose recognition Graton has recently proposed to cover those deposits which extend below the typical epithermal and are not yet typically mesothermal.

AGE AND SOURCE OF THE MINERALIZATION.

Mineralization in the Banner district has followed dike intrusion, for there is clean-cut evidence that the Panamint vein passes through a body of rhyolite porphyry, and has altered it hydrothermally. This porphyry, as well as other dike rocks in the district, is structurally and petrographically similar to those in the "porphyry belt" of the Boise Basin now receiving detailed study by the senior writer, and in turn similar to certain intrusives in the Lava Creek district [16] which invade Tertiary volcanic strata. Ross,[17] who has also examined the porphyries of the Boise Basin, correlates them with similar intrusives in south-central Idaho which invade the Challis volcanics, a thick sequence of lava flows and pyroclastics of early Miocene or late Oligocene age. He states that the ore deposits of south-central Idaho fall into two main classes;[18] those genetically related to the Idaho batholith, and those related to Tertiary igneous rocks. The Banner deposits, because of the post-dike relations, belong to the second of the two main periods of metallization and are therefore not to be

[15] Graton, L. C.: The Depth-zones in Ore Deposition. ECON. GEOL., vol. 28, pp. 536–540, 1933.

[16] Anderson, A. L.: Geology and Ore Deposits of the Lava Creek District, Butte County, Idaho. Idaho Bur. of Mines and Geology, Pamph. 32, pp. 13–26, 1929.

[17] Ross, C. P.: *Op. cit.*, p. 331.

[18] Ross, C. P.: Classification of the Lode Deposits of South-central Idaho. ECON. GEOL., vol. 26, pp. 169–185, 1931.

related to the Idaho batholith, the prevailing country rock, as Ross [19] has suggested.

The close association of the lodes or veins with the Tertiary intrusives along zones of regional shearing later than and transverse to the trend of the batholith suggests a common deep-seated source for the dikes and veins.

The precise age of the mineralization cannot be determined as yet from the available data, but is probably late Miocene or possibly early Pliocene. From data yet unpublished, it is known that the porphyry dikes in the Pearl-Horseshoe Bend district west of Boise Basin are younger than the Payette formation (middle or upper Miocene, according to Kirkham).[20]

SUMMARY

The narrow, high-grade silver veins in the Banner district consist largely of hypogene minerals at the greatest depth (nearly 600 feet) reached in mining. The deposits are notable for the relatively high proportion of silver sulphantimonides, particularly pyrargyrite and owyheeite. Mineral relationships are exceedingly complex, and centrifugal and pseudo-eutectic replacements are abundant as a result of hypogene silver enrichment. The mineralization, in spite of the abundance of the silver sulphantimonides, is not typically epithermal, but may belong in the deeper part of that zone or in the cooler part of the mesothermal.

The veins are far within the Idaho batholith, but in a great transverse zone of shearing along which Tertiary dikes have been intruded. Mineralization followed dike intrusion and therefore belongs to the younger of the two main metallizing epochs in south-central Idaho. Relations here suggest that similar silver lodes in south Idaho, heretofore regarded as related to the Idaho batholith and possibly of Mesozoic age, may also be genetically related to the younger magma of which the porphyry dikes are manifestations. This mineralization is probably late Miocene or perhaps early Pliocene.

UNIVERSITY OF IDAHO,
MOSCOW, IDAHO.

[19] *Op. cit.*, ECON. GEOL., vol. 28, p. 335.

[20] Kirkham, V. R. D.: Revision of the Payette and Idaho Formations. Jour. Geol., vol. 39, pp. 193–239, 1931.

EDITORIAL

PETROLEUM ENGINEER V. PETROLEUM GEOLOGIST.

THE spheres of activity of the petroleum engineer and the petroleum geologist grade imperceptibly into each other. No engineer can properly visualize his problems without a considerable background of geology. Conversely, the geologist can seldom arrive at sound conclusions without invoking principles of physics, mathematics and mechanics, which are the essential working tools of the petroleum engineer.

Geology came into prominence during a period when the search for new pools overshadowed the extraction of oil from pools already developed. The geologist continued throughout the years to develop a specialized technique directed toward oil discovery. He branched out into micropaleontology, paleogeography, and sub-surface correlation, and he began the study and interpretation of geophysical data. All his efforts were directed toward a search for favorable structure, on the assumption that structure was the prime factor in the accumulation of oil. He neglected to revive and perfect his knowledge of those subjects which might properly have entitled him to the title of geological engineer. And because he failed to visualize the problems of oil production and prepare himself for the very necessary task of recovering oil from the ground, a new profession of petroleum engineering came into its own. The geologist saw before anyone else that enormous reserves of oil were left below ground by early production methods; yet, as a class, he did nothing about it further than call attention to the fact. A few mechanically minded geologists began studying well operation, the mechanics of fluid flow, the physical properties of crude oil, the propulsive energy of gas; soon other capable engineers, not necessarily geologists, seized upon this very promis-

ing field, and in a few years a new technical group had evolved for themselves an indispensable place in the oil industry.

In a period of not more than ten years these two groups, the geologists and the engineers, have so far diverged that they have separate organizations and are even prone to believe that they have little community of interest. The geologist seldom attends the engineers' meetings because he is apt to hear a discussion of problems of corrosion, or have thrust upon him incomprehensible mathematical formulæ. The engineer is bored by discussions of fossils and has lost interest in the broad fundamental problems of stratigraphy. Accordingly many of the errors made by geologists are apt to be transgressions of simple laws of physics; and the errors of the engineer are too often traceable to faulty geological premises.

There is no fundamental and valid reason for the existence of these two professions as distinct entities. Their ideals and training should be the same. A capable and adaptable geologist, well versed in engineering, should handle equally well problems of oil finding or oil production. A predilection for mechanics or mathematics might shunt one man into production engineering; while the somewhat different talents of another might better qualify him for strictly geological pursuits. But the training of both groups before their entry into vocational work should be essentially the same. Except for a lack of vision, the geologist might today be serving also as the petroleum engineer.

W. E. Wrather.

DISCUSSION AND COMMUNICATIONS

THE MIAMI–PICHER ZINC–LEAD DISTRICT.

Sir: The August, 1933, number of this Journal contained a paper by Dr. W. A. Tarr, entitled "The Miami-Picher Zinc-Lead District." Referring to articles by Weidman [1] and Fowler and Lyden,[2] he states: "This article is written to take issue with these authors on their interpretation of the age and origin of the chert; also, to point out that to regard this chert as an original chemical deposit, formed simultaneously with the limestone of the Boone formation, makes possible a clearer, more logical, and more accurate account of the origin of the ores." His discussion covers: ". . . first, the origin of the chert (not the jasperoid), second, the origin of the chert breccias associated with the ores, and, third, the origin of the jasperoid and zinc-lead ores."

Dr. Tarr's paper contains numerous unsupported statements expounding his and other theories regarding the origin of the chert and chert breccias which, to the writers, carry little weight, even though he states: ". . . the writer's notes show that he favored this method of origin of the breccia over twenty years ago, even before his intensive study of chert, and a similar method of origin has been advocated by others," and that his ". . . studies of chert, especially of the larger nodules and lenses, have revealed that these silica aggregates are in a constant state of stress as they exist in the rocks," and:—"On the removal of the surrounding rock, this internal force becomes effective and aids in the mechanical disintegration of the chert mass."

[1] Weidman, Samuel: The Miami-Picher Zinc-Lead District, Oklahoma. Okla. Geol. Surv. Bull. 56, 1932. University Press, Norman, Oklahoma.

[2] Fowler, G. M., and Lyden, J. P.: The Ore Deposits of the Tri-State District (Missouri-Kansas-Oklahoma) (with Discussion). A. I. M. M. E., Tech. Pub. 446–I. 30. Jan., 1932.

Our discussion of Dr. Tarr's paper will be confined to some conflicts between his statements and our field observations. It should be evident to those who base their opinions upon actual field studies, that deformation, rather than solution, is primarily responsible for most of the chert breccia in this district. Dr. Tarr, being unfamiliar with the important structural features of the area and their relation to the chertification and to the localization of the ore bodies, minimizes or ignores them. His lack of acquaintance with the facts is evident from his statement on page 474, *i.e.*,

> Faulting had little to do with the localization of these galleries and shafts. . . . Strong major joint systems were apparently absent, as little alignment or definite arrangement of the ore bodies is noted in the maps representing them. The writer does not regard the various tension shear zones, postulated by Fowler and Lyden, as at all essential.

The positive identification of the beds of the Boone formation throughout the Tri-State District is, of course, the basis for knowledge regarding the structural deformation. The significance of the detailed stratigraphy of the Boone is so great that only by its consideration can the structure and alteration of the formation be understood.

A practical knowledge of the stratigraphy has enabled us to measure flexing and faulting in the beds and to establish the fact that every ore body in the Oklahoma-Kansas field is definitely related in some manner to structural features that have resulted from deformation. Adjustment of stresses by shearing and flexing is evident throughout the entire district, and in parts of it the structural displacement exceeds 300 feet vertically. These are facts about which it is unnecessary to elaborate further.

On page 465 Dr. Tarr says:

> Fowler and Lyden recognize that "minute quantities of silica were deposited with this limestone (Boone)," but state that outside the disturbed areas "little or no chert is found." They regard the Boone formation outside the Tri-State district as being free from chert, a conclusion that shows they are unfamiliar with the formation elsewhere.

The last sentence is unjustified since no such statement appears in our paper, and we had no intention of conveying this impression. We have noted chert elsewhere in the Boone, and in other limestone, in many parts of the Ozark Uplift and the Mississippi Valley generally. We have studied excellent exposures of chert in limestone near Osceola, Sedalia, Clifton City, Columbia, Missouri, and Eureka Springs, and in many other places in northwestern Arkansas. These occurrences appear to be similar to that of the chert in the Tri-State District, except that the deformation and chertification are much less intense. We limited our paper largely to the Tri-State District, and so stated on the first page.

Professor W. M. Agar of Columbia University made a microscopic study of 14 representative specimens from this district and reported as follows:

> There are two types of chert (as distinct from jasperoid). These are:
>
> (*a*) Older chert—composed of minute individual or linked globular masses of brownish chalcedony with a fibrous structure set in a mosaic of quartz grains from 0.03 mm. in diameter down to barely perceptible grains. Contains many sponge spicules now composed of slightly coarser quartz grains. Forms irregular or sharply angular fragments in jasperoid or in younger chert. In the latter case the boundaries between the two, though distinct, are not sharp.
>
> (*b*) Younger chert—varies from relatively clear to brown but without the well developed globular structure of type (a). It is also composed of cryptocrystalline silica and micro-fibrous chalcedony. It contains a few sponge spicules and a highly variable but usually large number of calcareous fossils in all stages of silicification. It grades into pure limestone and nowhere exhibits a sharp, distinct boundary.

From the above facts it is particularly important to note that the *younger* chert cemented the *older* chert breccia. The older chert is probably present in many places but is obscure. The younger chert is found in abundance throughout the district, but the relative proportion of it is unknown. Both are Mississippian in age. This sequence of events at once removes the possibility

of the syngenetic origin of the younger chert, the common and abundant type in this district. The brecciation and fragmental character of the older chert shows that it was subjected to deformation before being cemented by the younger chert. The two varieties were in turn brecciated by later deformation and recemented by the jasperoid, ore, and later minerals. Perhaps some of the differences of opinion regarding the origin of the chert are due to lack of study regarding the two varieties described above.

On page 466, describing the origin of chert, Dr. Tarr states:

> The chert in this formation (the Boone), as the writer has shown in the articles cited,[3] is primary, having been deposited with the limestone. Its distribution over thousands of square miles, the widespread occurrence of the chert in the same zone, its persistence along a given horizon within that zone, and innumerable other lines of evidence, prove its syngenetic origin.

We are fully aware of the widespread distribution of the chert and are not unmindful of the problem of accounting for its origin. But perhaps even that is not more difficult than to account for many other remarkable geological phenomena.

Intensive observations here, together with scattered observations elsewhere in the Mississippi Valley where chert is common, leave us no choice but the conclusion that the chertification was localized by structural conditions, which provided channelways for the movement of waters charged with silicic acid from some abundant source. Certainly, the chert is *not* uniformly distributed over given horizons. As to where it all came from, we too would very much like to know. We merely feel sure that it was introduced from elsewhere and replaced material that previously was limestone. It seems most likely that it came from the same general source that yielded the ore deposits, and as yet we see no reason to believe that these are not of hypogene origin.

The geological relationships show that the chertification in the Tri-State District is pre-Chester and is definitely related to the

[3] Tarr, W. A.: Origin of the Chert in the Burlington Limestone. Amer. Jour. of Sci., vol. 46, pp. 409–452, 1917. Origin of Chert and Flint. Univ. of Mo. Studies, vol. 1, 1926. In conjunction with Twenhofel, W. H.: A Treatise on Sedimentation, Baltimore, 1932.

first period of structural deformation. It was more intense in the two major mining fields of the district, the Joplin-Webb City and the Oklahoma-Kansas fields, than in any other part of the Ozark Uplift with which we happen to be familiar. Subsequent deformations reopened and intensified those of the first period. In these localized areas most of the limestone beds in the structural trends have been chertified; but outside and between the areas of zones of structural deformation, these same beds may contain little or no chert over areas ranging from a fraction of an acre up to many acres. In other words, the alteration of a given bed in the formation from pure limestone to partly or wholly chert has depended upon the extent to which the formation has been opened or shattered by deformation. The contact between limestone and chert varies in abruptness, as has been indicated elsewhere. The change from limestone to chert within a given horizon may be observed in many mines in the Oklahoma-Kansas field; for example, in the Bendelari Mine, in the drifts in M bed near the center of the mine; in the Barr Mine, in the long southerly drift in M bed; and in the Evans-Wallower No. 7 Mine, in the several drifts in M bed westerly into the tight ground from the mine workings. These locations are cited because they are accessible at the present time. There are many others where the same facts may be observed. Also, innumerable drill holes show the same range from limestone to chert and chert to limestone where the strata extend from undeformed through deformed zones to undeformed areas again.

The chert nodules offer much evidence of the secondary nature of the chert, both in the manner of their distribution and in their interior structure. Following nearly completely chertified strata in which chert nodules are abundant, from zones of structural deformation into undeformed limestone, the proportion of chert in the bed as a whole gradually peters out and the nodules become smaller and smaller and more widely spaced, and at last disappear entirely. The distance necessary to complete such a cycle varies greatly.

With the structural relationship of chert to limestone so ob-

vious, we find difficulty in substituting a conception of the marine deposition of silica within the original calcareous deposit in such a manner as would account for the present concentration of the chert in the zones which were deformed at a period remote from the initial deposition of the limestone.

Vertical exposures along bluffs may sometimes appear to verify the assumption that the beds are everywhere chertified. But usually such bluffs are themselves expressions of structural features similar to shear zones observable underground. And, as Dr. Dake has pointed out, the horizon may be quite lacking in chert a short distance in from the face of the bluff.

Dr. Tarr further does not reveal adequate familiarity with the chert of the Tri-State District nor of the Boone formation as a whole by the statement which he makes on page 470: "The original distribution of the chert was uniform along or within a given bed in the limestone." As is repeatedly noted in this paper, the chert certainly is not now uniformly distributed along or within any given bed, and we fail to see what evidence Dr. Tarr may have that it ever was so distributed.

We repeat, that the distribution and manner of occurrence of the chert, so obviously related to structure and so commonly ending abruptly in strata that are continuous, is ample evidence to us that the chert is not syngenetic with the limestone.

Regarding Dr. Tarr's criticism of the term "chertification," we found that "silicification" has so many meanings and is applicable to so many types of rocks that we felt forced to coin the term "chertification" to express the definite concept of the replacement of limestone by silicic acid to form chert. Obviously, his objection that the term "is just another piece of excess baggage in our literature . . ." rests upon his conception that the chert is syngenetic.

As to Dr. Tarr's statement on page 466 that chert "beds that are 10, 20, 50, or more feet thick are known," we fully agree that there are many places where the beds of chert are locally of the thicknesses mentioned, but if Dr. Tarr would follow these same beds away from the zones of deformation he would find them to become predominantly limestone.

On pages 470 and 473, under the headings "Underground Circulation" and "Breccia Formation," Dr. Tarr submits a long discussion in which he offers no specific field data nor information concerning the respective beds or the horizons in which underground circulation takes place, other than the following statement on page 471: "The movement of underground water was facilitated by the presence of chert lenses and nodules, but was especially active in the Grand Falls (Boone) chert horizon. The solution channels followed this horizon chiefly but also extended upward and downward." This statement is not supported by our field observations.

The so-called Grand Falls horizon, which falls within our O, P, and Q beds in the Oklahoma-Kansas field, and is not everywhere chert, is not the chief horizon followed by solution channels and is relatively unnotable in this respect. The horizons 25 to 100 feet above the Grand Falls, and especially M bed in our classification, furnish much better examples of solution channels and brecciation, and especially of mineralization. To date, only four mines in the main Oklahoma-Kansas field have found commercial ore bodies in the Grand Falls horizon. These mines lie within an aggregate area of 240 acres out of 25 square miles of mining territory in this particular field. The Grand Falls horizon is more important in the Baxter Springs area to the northeast of the main Oklahoma-Kansas field, where it compares favorably with the upper horizons. In the Southwestern Missouri zinc-lead districts it was the most important horizon.

In his summary on page 479, Dr. Tarr reiterates his belief that ". . . the chert of the Boone formation . . . is primary or syngenetic and was deposited chemically on the sea floor at the time of the deposition of the enclosing limestone beds" and that ". . . this view is in keeping with the latest theories as to the origin of chert."

Theories, of course, to be of any value must explain the facts. Obviously Dr. Tarr is not familiar with the essential facts regarding the distribution of the chert and of the ore bodies in the Tri-State mining field.

G. M. FOWLER AND J. P. LYDEN.

JOPLIN, MISSOURI.

SERPENTINIZATION: ORIGIN OF CERTAIN ASBESTOS, TALC AND SOAPSTONE DEPOSITS.

Sir: The problem of serpentinization, discussed by H. H. Hess[1] in this Journal, is an important contribution to the subject but is subject to criticism in certain parts; examination of a larger number of the Vermont talc and serpentine masses would have forced him to look for additional microscopic structures which would have altered materially most of his conclusions. Since many of these are of economic importance in the search for verde antique and talc, I offer the following contribution to correct certain inaccuracies that might become rooted in the literature.

Hess holds (p. 639) that,

> The intrusions are concordant bodies, commonly lenticular in shape, individual lenses varying from 40 feet wide by 100 feet long to four times that size; but less commonly they occur as pinching and swelling sheets.

The Moretown lens—a moderate-sized one—is 5500 feet long by 500 feet wide.[2] Most of the other statements to which I do not subscribe arise from lack of sufficient size range in ultrabasics examined, and omission of mapping distribution of unchanged ultrabasic, serpentine and talc. Specifically, the following conclusions seem out of harmony with observed distribution of serpentinized and steatitized masses in Vermont ultrabasics:

1. Amphibole is an early mineral in the talc deposits.
2. Serpentine and chrysotile veins remain in the ultrabasic.
3. Serpentinization is due to causes originating within the ultrabasic.

Position of Amphibole in the Mineral Sequence.—Distribution of radiating actinolite in greater abundance along the walls than through the ultrabasics in Vermont, argues strongly against its early development. Coarse radiating actinolite appears independent of talc in only one ultrabasic out of over one hundred and fifty that have been mapped. (Other amphiboles are distributed irregularly through many of the serpentines; they follow the

[1] Hess, H. H.: Serpentinization: Origin of Certain Asbestos, Talc and Soapstone Deposits. ECON. GEOL., vol. 28, pp. 634–657, 1933.

[2] Bain, G. W.: Chrysotile Asbestos; II, Chrysotile Solutions. ECON. GEOL., vol. 27, p. 291, 1932.

serpentine-chlorite stage and precede the talc stage). This actinolite is found only in those masses that have been moderately to completely steatitized. This general rule applies to ultrabasics ranging from one in Westfield which has no talc, to those extreme examples in Weathersfield and in Rowe, Mass., where the entire mass is steatitized and parts are changed to hornblende schist.

The Holden Soapstone quarry is not a good place to study steatitization. An amphibolitized andesite cut by acid dikes forms part of the wall. Exposures of soapstone are poor and the steatitized mass may be altered from this amphibolite rather than from a typical ultrabasic. The soapstone is a massive chlorite rock partly replaced by rosettes of needle-like talc crystals. Hess regards these as pseudomorphs after amphibole (p. 644). The evidence is not conclusive at the Holden quarry, but a deposit south of the Randolph Gap road eastward from Rochester has similar radial talc in similar massive chlorite along the wall of the ultrabasic. Crystal cross-sections resemble those of an amphibole; sections parallel to the length of the acicular talc show "ghost" outlines of chlorite flakes and cleavage "ghosts" continuous with those in bordering chlorite. This indicates direct alteration of the chlorite to acicular talc along the line of growth of the talc crystal; the form is the talc growth form and not an amphibole replacement which it resembles. This acicular form of talc has a remarkably limited size of cross-section—up to one millimeter—where it occurs in chlorite. The radial actinolite ranges from 0.01 millimeters to 30 millimeters in cross section. If the talc is pseudomorphous after actinolite, size range in the two minerals ought to be comparable.

Talc from the Vermont Mineral Products mine is pierced by extremely delicate sprays of actinolite needles; each spray concentrates into a single crystal and these radiate from a base of biotite or chlorite wall or horse. Several very perfect, unbroken, delicate needles were separated from the talc. Conspicuous folding in the talc appeared on the smooth amphibole contact plane; the delicate actinolite would have been broken had it antedated the crumpling. Likewise, amphibole in the Randolph Gap ultra-

basic is undeformed and cuts across a schistosity in the older chlorite and serpentine. In each case a period of minor deformation preceded the actinolite introduction, and followed the serpentine, chlorite and talc formation. The weight of evidence still seems to favor a rising-temperature mineral sequence of serpentine or chlorite, talc, actinolite or biotite, and lastly hornblende or muscovite.[3]

Limitation of Distribution of Chrysotile Veins.—As Hess states (argument 3, p. 649) "the chrysotile veins are limited to the ultrabasic"; but chlorite veins, essentially similar to the chrysotile veins in the ultrabasic, appear around the Trowsers Lake body in southern Quebec, and about the Moretown and upper East Granville talc deposits in Vermont, where the wall-rock is approximately similar to the ultrabasic in competence. It was suggested that the paucity of veins outside the ultrabasic is due to relative competence of the two rock types. This wider distribution of veins of the chrysotile system weakens the argument for an endometamorphic origin of serpentine.

Distribution of Serpentinization.—During the years 1928–30 I mapped the distribution of talc, serpentine and unchanged saxonite and dunite in more than 150 bodies extending from Eastman, Quebec, to east of North Adams, Mass. Masses approximating a half-mile long by 300 feet wide or larger are the only ones where the entire rock has not been changed. Serpentinization has been cited as limited to borders of fractures of tectonic origin;[4] serpentine in the center of the peridotite, shown on Keith's map,[5] lies along a highly fractured zone, and the verde antique or serpentine at Moretown occurs only in the most fractured part of that great lens. Alteration of the saxonite is absent or incomplete outside the fractured zones. As stated by Hess (argument 2, pp. 648–649) serpentinization bears no relation to the borders of the ultrabasic; but from the above it is evident that it does bear a very definite relationship to fractured zones in the

[3] Bain, G. W.: *Op. cit.*, pp. 292, 295.

[4] Bain, G. W.: *Op. cit.*, p. 284.

[5] Keith, S. B.: Chrysotile Asbestos; I, Chrysotile Veins. ECON. GEOL., vol. 27, p. 178, 1932.

saxonite and is incomplete outside of them. These fracture zones post-date crystallization of the ultrabasic by a considerable period.

Hydrothermal Origin of Serpentine.—Hess states (argument 5, p. 650) that:

> Perhaps fifty hydrothermally altered (steatitized) ultrabasics were examined, and in every case chlorite, not serpentine, was developed.

From the discussion it is to be inferred that these ultrabasics were in Vermont. If anyone will take me to an ultrabasic in Vermont, and if they will exclude one small body in Westfield and one in North Troy, I will take them to a talc body in it. This seems to conflict with the statement that serpentine is not developed in steatitized ultrabasics.

At another place (argument 4, p. 650) Hess admits magnetite as one of the minerals of the serpentinization process but makes chlorite an index of hydrothermal alteration. Magnetite in verde antique serpentine does not polish satisfactorily, and I have been called upon to study its occurrence in this type of stone. Although every slab of verde antique produced has not come to my attention, those I have studied have a rim of chlorite around all magnetite grains. The magnetite and chlorite seem to have the same origin, whatever that may be; generally it seems to be a change that accompanies serpentinization and is related to the alteration of serpentine to talc.

Chlorite is very abundant in the walls of the ultrabasic adjacent to the talc deposit but the best quality of verde antique serpentine borders this talc-chlorite-carbonate zone. These close associations in distribution and sequence of development in rocks ranging from dunite to pyroxenite indicate to me that serpentinization, steatitization, and development of amphibole are not related to deuteric activity of the parent magma but are later hydrothermal changes that advance into the ultrabasic from solution channels, in the order mentioned. Certainly Hess' arguments 2, 3, 4, and 5 seem to fail when subjected to the test of specific cases.

GEORGE W. BAIN.

AMHERST, MASS.

REVIEWS

Mineral Deposits. By WALDEMAR LINDGREN. Pp. 930; figs. 333. McGraw-Hill Book Company, New York and London. 4th Ed., 1933. Price, $6.50.

Lindgren's well-known text book has again proved its value by appearing in a fourth edition, revised and reset. Inasmuch as the first edition was published 20 years ago, the new volume may appropriately be reviewed as a whole, rather than by dwelling on changes made from the third edition.

The central plan of the book is the treatment of mineral deposits in accordance with a grouping based on the temperature, and correlatively on the depth, of their formation. In the preface to the first edition, the author expressed some doubt whether the time had arrived for such a genetic classification, but the results have justified his attempt, the classification has been widely used, and, in the preface to the fourth edition, he is able to make the interesting generalization that the epithermal gold and silver deposits in the United States are those for which exhaustion is most imminent.

The first two chapters are essentially introductory. They deal with the distribution of the chemical elements in the earth, their general modes of concentration into mineral deposits, and the fundamental physical and chemical conditions under which minerals form. Perhaps in these chapters more emphasis might have been laid upon the extremely small proportion of the useful and precious metals (except iron and aluminum) present in the earth's crust as a whole, and the consequent extraordinary concentration that has taken place in the formation of an ore body. It has been calculated that all of the metals valuable to man, except the two mentioned, are among the constituents that together compose only about 0.4 per cent. of the earth, to a depth of about 10 miles. Realization of this fact suggests that ore deposition is rarely a simple process but depends for its occurrence upon the coincidence of a number of favorable conditions or circumstances, which as yet are only in part known.

Chapters III to V are devoted chiefly to the movements and composition of underground water, the author clearly recognizing, as appears later, that the majority of ore deposits have been deposited from aqueous solutions. Among the generalizations here reached are: (1) that water

in sufficient quantity to supply an ascending current can exist only exceptionally below a depth of 10,000 feet; (2) that waters initially acid cannot travel far underground without becoming neutral or alkaline. To the reviewer, the limiting depth of 10,000 feet appears to be too small. The argument for so restricted a depth range appears to be based on conditions as observed in mines *after* openings have been mineralized or sealed, rather than to those obtaining immediately before mineralization began.

Chapter VI logically treats of the deposits which, as shown by observation, are made by springs, at the earth's surface. Among minerals formed in this way are listed sulphur, quartz, opal, chalcedony, limonite, wad, psilomelane, calcite, aragonite, siderite, strontianite, barite (in part plumbiferous), gypsum, celestite, fluorite, scorodite, pyrite, marcasite, realgar, orpiment, cinnabar, stibnite, chabazite, apophyllite, stilbite, and probably adularia.

Chapter VII discusses more directly the relationship between mineral springs and ore deposits. It is concluded that deposits of quicksilver, antimony, arsenic, gold and silver may be formed close to the earth's surface by thermal spring-waters of the kinds related to volcanism, and that warm or cold waters of meteoric origin are capable of forming deposits of the common base metals. The waters most competent in this respect appear to be calcium bicarbonate solutions and sodium chloride waters containing carbon dioxide and hydrogen sulphide.

The chapter on the origin of underground waters is short and rather disappointing in its inconclusiveness. The author, however, sums up fairly the evidence for juvenile *versus* meteoric water, as the principal agent in ore deposition. He clearly does not regard the problem as solved and in this respect declines to align himself with the members of the thorough-going panmagmatic school which, at the present time, sets the fashion in the theoretical discussion of ore genesis, and whose members, undaunted by the significant record of history, regard their views as final.

In Chapter IX is discussed the general relation of mineral deposits to metamorphism, a connection which appears to have been first clearly recognized by Charles Darwin. Here Lindgren formulates his law of equal volume in replacement and makes the generalization that "the great majority of ore deposits have been formed within 15,000 feet of the surface," whereas L. C. Graton has recently suggested that hypothermal deposits may form at depths as great as 10 to 20 miles.

The relation of magma to mineral deposits, a large, intricate, and controversial subject, is concisely treated in the 27 pages constituting Chapter X. It is here maintained "that the hypothermal and mesothermal deposits are formed by emanations from intrusive rocks, generally batho-

liths. It is also thought that the epithermal deposits are formed by emanations from very deep magma chambers in which the differentiation of the lavas is proceeding." This indicates closer conformity with the prevailing mode of thought than is shown in the discussion of underground waters. It is essentially the view that most hypogene ore deposits are end-products of magmatic differentiation, as maintained by Niggli and many other investigators. The zonal theory of ore deposits Lindgren regards as "a rather weak structure," yet, as was recognized long ago by Von Cotta, it would appear to be a logical and necessary consequence of the direct magmatic derivation of ore deposits. He believes that the silica has been carried in colloidal solution and has been deposited as a gel.

Folding and faulting are treated in Chapter XI, and Chapter XII discusses openings in rocks. It is believed that the force exerted by growing crystals has played a wholly minor part, and the more probable idea that fissures may be widened by the hydrostatic force of injected solutions is ignored.

The following two chapters are devoted successively to the form and structure of mineral deposits and to the texture of mineral deposits. In Chapter XV, ore-shoots are discussed with relation to form, succession, and causes of localization. The most important factor in deposition is believed to be decreasing temperature, although pressure, kinds of wall rock, impervious barriers, and fissure intersections may play local or minor parts.

The classification of mineral deposits forms the subject of Chapter XVI. After a brief review of some earlier classifications, Lindgren proposes his own scheme, based on processes and temperature of deposition. He makes two major divisions—deposits formed by mechanical concentration and deposits formed by chemical concentration. The chemical concentrates he groups as (*A*) those formed in bodies of surface water; (*B*) those formed in bodies of rocks; (*C*) those formed in magmas, by differentiation. Under *B*, he distinguishes: (1) those formed by concentration of substances previously present in the geologic body in which they are found; (2) those formed by the introduction of substances foreign to the rock body in which they are found. The deposits under *B* (2) are grouped as: (*a*) Deposits formed independently of igneous activity by circulating atmospheric water, and (*b*) those dependent upon the eruption of igneous rocks. These last are further divided into; (*a*) Deposits formed by hot ascending waters of uncertain origin but charged with igneous emanations, and (*b*) those formed by direct igneous emanations. Deposits (*a*) are in turn subdivided as *epithermal*, *mesothermal*, and *hypothermal*.

The classification, here given only in outline, is logical and has proved its utility. The place within it to which a particular deposit is assigned,

however, must depend largely upon the views held as to ore deposition in general. Being based largely upon theoretical considerations of genesis, it can scarcely be satisfactory to the at present submerged group whose members still see some merit in the broad lateral secretion views, such as were held by S. F. Emmons, Joseph Le Conte, and C. R. Van Hise, or to those who like J. E. Spurr, have reintroduced, in modern dress, the theories of Hutton, Fournet, and Belt.

Deposits formed by mechanical processes are treated in Chapter XVII, and here are included the auriferous conglomerates of the Rand, although Lindgren is evidently not entirely satisfied with the adequacy of the detrital hypothesis. He suggests that the layers of banket may represent detrital deposits slightly enriched by hydrothermal processes. This position, however, appears to be a rather difficult one to maintain.

Chapter XVIII deals with deposits formed by chemical processes. Here are included the unmetamorphosed sedimentary iron and manganese deposits, limestone, phosphates, etc. It is not easy to see why many residual deposits, such as those of clay, bauxite, limonite and garnierite, should not belong here, rather than with deposits in bodies of rock. The regionally metamorphosed iron ores, such as those of Lake Superior, are assigned a chapter to themselves (No. XX).

Under the general heading of mineral deposits formed in bodies of rock by concentration of substances contained in the rock itself, are described deposits resulting from rock decay, or residual deposits (Chapter XXI), and deposits concentrated by circulating waters (Chapter XXII). In the latter group are included such miscellaneous materials as sulphur; serpentine; magnesite; talc; soapstone; asbestos; pyrophyllite; andalusite; barite; ores of copper, lead, vanadium, and uranium in sandstone and shale; and copper sulphide veins in basic lavas and basic intrusive rocks. Whether these all belong under this genetic head is open to question.

Under the general head of ore deposits due to concentration within a rock-body of substances originally foreign to the rock, attention is given, in Chapter XXIII, to those formed independently of igneous activity, by circulating meteoric water. Here are included the lead-zinc deposits of the Mississippi Valley, of Silesia, of Moresnet, and of the Alpine Trias. The origin of these deposits is still warmly debated and it is questionable, in more respects than one, whether they have found a final resting place in a genetic scheme of classification.

Under deposits dependent upon the eruption of igneous rocks, the epithermal deposits are treated in Chapter XXIV and the characteristics of typical examples are excellently described.

Chapter XXV deals with deposits of native copper, and obviously the

author has been unable to fit these into his genetic classification, although he suggests that they should probably be grouped with the epithermal deposits. As regards the most important examples, those of the Lake Superior region, this suggestion appears scarcely acceptable.

The large group of mesothermal deposits is considered in Chapter XXVI, of 108 pages. Of course there may be some question as to the inclusion of some particular individual deposits in this group, but as a whole the characteristics of the group are clearly drawn, and in distinguishing these deposits from the epithermal deposits on the one hand and the hypothermal deposits on the other hand, Lindgren has made a highly important contribution to the theory of ore deposits.

The hypothermal deposits are discussed in Chapter XXVII, followed by an excellent chapter on pyrometasomatic deposits. Chapter XXIX deals with regionally metamorphosed sulphide deposits. The reviewer questions whether more than sulphide deposits might not well have been included here, and the zinc deposits of Franklin Furnace described in this chapter, rather than under pyrometasomatic deposits.

Chapter XXX treats briefly of the mineral deposits of the pegmatite dikes. The author's use of *complementary* as applied to dikes is inaccurate, and it is not easy to justify the use of the German *rest magma* for residual magma.

In Chapter XXXI, under deposits formed by concentration in molten magma, are described, among other deposits, the copper-nickel ores of Sudbury, although this view of their genesis is not accepted by all.

Chapter XXXII treats satisfactorily of the oxidation and enrichment of ores. The author uses the terms *supergene* and *hypogene* in the text, but the diagrammatic illustration on page 816 (fig. 314) has not been revised to accord with this nomenclature.

The concluding chapter, on metallogenetic epochs, reviews the relation of mineral deposition to mountain-building and igneous intrusion, as displayed throughout geological history in various parts of the world.

It is characteristic of the book that the views expressed are never extreme and, to some, doubtless appear ultra-conservative. On many disputed points the author frankly withholds his judgment, regarding the evidence as too conflicting or insufficient for final decision.

For a work involving so much digestion and compilation from many sources, the errors are remarkably few, and those noted are unimportant.

The treatment of deposits on the basis of genesis, rather than by metals or uses, is scientifically interesting but has certain disadvantages from a practical point of view and, partly because of such arrangement, the book is rather difficult reading for all but advanced students. Nevertheless, in the reviewer's opinion, it is outstandingly the best text-book on

ore deposits in English and the most satisfactory one-volume text in any language.

F. L. RANSOME.

BALCH GRADUATE SCHOOL OF THE GEOLOGIC SCIENCES,
CALIFORNIA INSTITUTE OF TECHNOLOGY,
PASADENA, CALIFORNIA.

The Determination of the Feldspars in Thin Sections. By K. CHUDOBA. Trans. by W. R. KENNEDY. Pp. 61, figs. 50. Thos. Murby & Co., London, 1933. Price, 6s. 6d.

This translation of Dr. Chudoba's concise description of practical methods for the determination of the feldspars in thin sections of rocks will be welcomed by many students to whom the reading of German is a task, more particularly in the cases where accuracy in sense is demanded. The original text is condensed and the language employed is precise (see this Journal, Vol. 27, p. 682); consequently the exact significance of the discussions so clearly presented by the author may be difficult to understand clearly unless the reader is fairly familiar with German. Fortunately the translator has put everything into English in such a way as to avoid any distortion of the author's treatment, with the result that he has given us one of the most satisfactory expositions of the diagnostic optical properties of the feldspars that has appeared for the use of English-reading students. The purpose of the volume is limited to the explanation only of those properties of feldspars that are of determinative value, and to illustrations of the methods employed in their use. It contains no statements of the relations of these properties to crystallographic features; the reader is supposed to be familiar with the principles of optical crystallography. The book is not only of value to beginning students in petrography but is also a very convenient one for the practiced petrographer to have at hand for consultation.

W. S. BAYLEY.

Erdölkrise? Ein Kurzer Überblick über die Gesamte Öltechnik und Ölwirtschaft. By K. KRÜGER. Pp. 62, figs. 3. E. Schweizerbart'sche Verlagsbuchhandlung. Stuttgart, 1934. Price, $1.20.

In a comparatively few pages the author summarizes the conditions in the oil industry, with special reference to their bearing upon the welfare of the German Empire. He briefly outlines the importance of petroleum in modern life and describes very succinctly its character, the methods of obtaining it and the comparative efficiency of those methods, the means employed in transporting it, etc. The different products of which it is the source and their uses are outlined and the characters they should

possess are stated. He then discusses the substances that may be substituted for some of the petroleum products. This is followed by a description of the petroleum occurrences in Germany and of the difficulty of securing new supplies sufficient to satisfy the needs of the country either from natural sources or from these with the addition of manufactured substitutes. The booklet closes with a listing of the large oil companies in the world and an estimate of their respective importance; and a statement of the condition of the industry in all producing countries, with a word here and there of their future prospects. There is not much that is new in the brochure, but it is a handy little summary of the oil business as a whole.

BOOKS RECEIVED.

By

DAVID GALLAGHER.

Outlines of Physical Geology. C. R. LONGWELL, A. KNOPF, AND R. F. FLINT. Pp. 356, figs. 297. Wiley & Sons, New York, 1934. Price, $3.00. An abbreviated version of "Physical Geology" by the same authors, rewritten to supply a text for a short course in physical geology. Clearly written; many new block diagrams and photographs; recommended.

The Drama of the Weather. SIR NAPIER SHAW. Pp. 269; figs. 92. Macmillan Co., New York, 1933. Price, $3.50. A book, neither text nor reference, popularly written, with many good pictures and diagrams, that rambles in leisurely fashion among things meteorological and incidentally, under disguised headings, gives some information about the weather, particularly British weather.

Discovery of Rock Salt Deposit in Deep Well in Union County, Arkansas. By H. W. BELL. Pp. 21, figs. 2, 1 table. Arkansas Geol. Surv., Inf. Circ. 5. Little Rock, 1933. Detailed geologic record of the deepest hole in the East Smackover Field.

Contributions to Canadian Mineralogy. Pp. 64, figs., pls. Univ. of Toronto Studies, Geol. Ser. 35. Toronto, 1933. Eight papers by different authors on Ontario Museum, Tungstite, The Errington Diamond, Photo-phosphorescence, Plagioclase, Specific gravity determined from refractive index liquids, Apatite, and Minerals of the Miller Lake O'Brien Mine.

Mining Operations and Statistics, Quebec Bureau of Mines, Annual Rpt., 1932, Pt. A. Pp. 158, pls. 6. Quebec, 1933.

Ontario Dept. Mines, 42nd Annual Rpt. Vol. XLII, 1933. Toronto, 1933. In three parts. Pt. I, Mine statistics, production, accidents. Pt. II, Erosion and Sedimentation at Point Pelee, by E. M. Kindle. Pt. III, four papers on lignite and clay.

Mineral Statistics for 1932, and Metal Production of Ontario for the First Nine Months of 1933. By W. R. ROGERS AND A. C. YOUNG. Pp. 8. Ontario Dept. Mines, Bull. 90. Toronto, 1933.

Microscopic Determination of Nonopaque Minerals, 2d Ed. E. S. LARSEN AND H. BERMAN. Pp. 266, figs. 7. U. S. Geol. Surv. Bull. 848, 1934, 20c. The same useful tables brought up to date and additional tables assembling the data of some of the most important mineral groups.

Mineral Industries of Canada, 1933. A. H. A. ROBINSON. Pp. 116, pls. 34, map. Canada Dept. Mines, Mines Branch, No. 738. Ottawa, 1934, 25c. Occurrence, production, uses, etc., arranged by products in alphabetical order.

Quebec Bureau of Mines, Ann. Rpt. 1932, Pt. C. Quebec, 1933. Two papers: Beattie Gold Mine, J. J. O'Neill, pp. 27, figs. 4, pls. 4; Arntfield-Aldermac Mines Map Area, E. L. BRUCE, pp. 87, figs. 10, pls. 4.

Geology of the Tuungsten Deposits Near Mill City, Nevada. P. F. KERR. Pp. 46, figs. 29. Univ. Nevada Bull. vol. 28, no. 2. Reno. 934, 40c. Chief producer in U. S. Contact metamorphic scheelite in limestone associated with hornfels and granodiorite.

Mineral Industry of New Jersey for 1932. M. E. JOHNSON. Pp. 21, pls. 4. N. J. Dept. Conserv. and Devel. Bull. 41, 1934. Statistical, industrial.

Some Lode Deposits in the Northwestern Part of the Boise Basin, Idaho. C. P. Ross. Pp. 46, pls. 9, figs. 4. U. S. Geol. Surv. Bull. 846–D, 1934, 35c. Three types of sulphide lodes of two ages and with interesting relationship to dikes.

Preliminary Report on Ground-Water Resources of Northern Virginia. R. C. CADY. Pp. 48, pl. 1, figs. 3, tables 17. Virginia Geol. Surv. Bull. 41, University, 1933.

Reconnaissance in Southern Shan States, and Geology of Country between Kalaw and Taunggyi. J. C. BROWN AND V. P. SONDHI. Pp. 113, pls., geol. map in color. India Geol. Surv. Records, vol. 67, pt. 2. Calcutta, 1933. Rs. 2–12 or 5/.

Sierra Leone, Report of the Geological and Mines Department for 1932. J. D. POLLETT AND A. J. W. LEGGE. Pp. 16. Freetown, 1934, 2/6.

Rhodesian Mining and Engineering Year Book, 1934. S. R. POTTER, Editor. Pp. 292, many figs. Issued annually in January by the S. A. Mining Jour. Synd., Ltd., Johannesburg; 10/6, postage extra. History and present status of all the mines, including a wealth of information and description.

Aerial Survey Operations in Australia During 1932. W. G. WOOLNOUGH. Pp. 78, pls. 2. Comm. of Australia, 1933. Results of an ap-

parently very interesting new technique in areal photography, but details of the method are omitted for want of space.

Deutsches Bergbau Jahrbuch, 1934. H. Hirz and W. Pothmann. Pp. 443, figs. Wilhelm Knapp, Halle (Saale), 1934, RM 14.50. Catalog of mines.

Investigations of Mineral Resources and the Mining Industry (Canada), 1932. L. H. Cole, R. K. Carnochan, and S. C. Ells. Pp. 29, figs. 5. Canada Dept. Mines, Mines Branch No. 735. Ottawa, 1934. Silica near Gatineau Point, Que.; sandstone at Hawkesbury, Ont.; bituminous sands of northern Alberta.

Suslota Pass District, Upper Copper River Region, Alaska. F. H. Moffit. Pp. 25, pls. 1. U. S. Geol. Surv. Bull. 844-C, 1933, 15c. Descriptive geology, geologic map in color.

Mineral Deposits and Placer Concentrates of Rampart and Hot Springs Districts, Alaska. J. B. Mertie, Jr., and A. E. Waters, Jr. Pp. 83, pls. 3, figs. 1. U. S. Geol. Surv. Bull. 844-D, 1934, 10c. Brief regional geology; descriptions of gold and tin placers.

Lode Deposits of Fairbanks District, Alaska. J. M. Hill. Pp. 145, pls. 8, figs. 24. U. S. Geol. Surv. Bull. 849-B, 1933, 35c. Regional geology; history, production, geology, and probable futures of the gold, antimony, and tungsten mines.

Willow Creek Gold Lode District, Alaska. J. C. Ray. Pp. 64, pls. 10, figs. 10. U. S. Geol. Surv. Bull. 849-C, 1933, 20c. General geology, economic geology, and descriptions of the mines.

Lode Deposits of Eureka and Vicinity, Kantishna District, Alaska. F. G. Wells. Pp. 44, pls. 5, figs. 2. U. S. Geol. Surv. Bull. 849-F, 1933, 20c. Regional and economic geology; descriptions of mines; gold, silver, copper, lead, zinc, and antimony vein deposits.

Valdez Creek Mining District, Alaska. C. P. Ross. Pp. 48, pls. 2, figs. 5. U. S. Geol. Surv. Bull. 849-H, 1933, 15c. Stratigraphy, petrology, structural and economic geology; placers, lodes; suggestions for development.

Past Placer-Gold Production from Alaska. P. S. Smith. Pp. 6. U. S. Geol. Surv. Bull. 857-B, 1933, 5c. Statistical.

Errata: The Rich Ores of Goldfield, Nevada,
C. F. Tolman and J. W. Ambrose,
Economic Geology, vol. XXIX, May, 1934.

Page 267: Formula for tennantite should read:—

$$Cu_3AsS_3 + x(Fe, Zn)_6As_2S_8$$

Page 278: Deposition lines for Au and Ag should not extend to the left beyond the termination of the goldfieldite line in Table II or of the Cu and Sb lines in Table III.

SCIENTIFIC NOTES AND NEWS

W. A. Parks, of the University of Toronto, has been elected to the Fellowship of the Royal Society of London.

A. K. Snelgrove, of the department of geology at Princeton University, has received the appointment of consulting geologist for the Government of Newfoundland.

C. O. G. Larcomb, after 27 years as lecturer on geology and mining at the Kalgoorlie School of Mines, has resigned to take up private practice.

John G. Barry, of El Paso, Texas, has resigned as President of the College of Mines and Metallurgy and has resumed private practice, with an office at 808 Mills Building.

Harold Titcomb has left the United States for London and Serbia.

W. S. McCann has returned from South Africa to London.

H. DeWitt Smith, of New York City, has gone to Vancouver and will be absent from New York for from one to two months.

S. J. Schofield and Irvine M. Marshall, of Vancouver, B. C., have formed a partnership as consulting geologists but will retain their present positions in the University of British Columbia and with the Reno Gold Mines, respectively.

B. Dale Condit, of Los Angeles, Calif., is in Australia making an extensive survey of oil possibilities there.

Chester W. Washburne recently lectured on Normal Faulting at the University of Michigan, the University of Chicago, and Northwestern University.

Thomas S. Carnahan, of the Union Minière du Haut-Katanga, came to the United States recently on account of the death of Mrs. Carnahan, and is in Los Angeles, California.

Waldemar Lindgren was presented with a finely bound copy of the Lindgren Volume containing a special frontal page bearing the signatures of the editorial committee, at a dinner arranged by the officers of the American Institute of Mining Engineers, held in New York on May 14. About fifty attended the dinner, including several of the editorial committee. L. C. Graton made a fitting speech, and the presentation was made by D. H. McLaughlin. Professor Lindgren replied in his inimitable manner.

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